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PALEOZOIC SUBMARINE LANDSLIPS NEAR QUEBEC CITY

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ABSTRACT

The following paper is an international attempt to explain the peculiar and interesting "conglomerates" at Quebec and Lévis as submarine landslips in the earlier stages of the development and deformation of a geosyncline. Since the discovery of undoubted ancient tillites and stratified drift in the Paleozoic, there has been a tendency on the part of American stratigraphers to overemphasize the necessity for a glacial origin of some extremely heterogeneous conglomerates and breccias. The authors of this paper review the history of the Quebec controversy from 1860 to the present day and compare the phenomena of the Quebec and Lévis "conglomerates" with those of the Wildflysch and *blocs exotiques* of the Alps; the Kimmeridgian boulder beds at Brora, Scotland; etc. The origin of the Quebec conglomerates should not be studied as an isolated phenomenon, but must be considered in relation to the history of the geosyncline in which they occur. It remains to test the hypothesis from this general point of view, especially in the field. Finally, the subject transcends the mere origin of the conglomerates and has a direct bearing on paleogeographic problems, such as the presence or absence of land barriers in the Eo-Paleozoic of Eastern Canada.

THE 1860 REFORMATION

Quebec occupies a proud position in the history of stratigraphy, tectonics, and paleogeography. It owes much of this distinction to certain peculiar conglomerates or breccias[1] that may be conveniently studied both in the city itself and at Lévis across the St. Lawrence. Attention was directed to these conglomerates as early as 1827 when Bigsby wrote of "a slaty series . . . . alternating with calcareous

[1] The boulders and pebbles of these accumulations are so little rounded that the universally employed title "conglomerate" is of doubtful validity.

conglomerates in beds, some of which are charged with fossil."[1] He recorded "trilobites, encrinites, corallines, and other fossils" in the Lévis conglomerates and regarded them as derived, in part at least, from the neighboring Trenton limestone.[2] In June, 1860, this rich fauna was rediscovered by Logan and Head. Thanks largely to the influence of Barrande, the time was now ripe for progress. Billings recognized an unexpectedly early aspect in the fauna, strongly rem-

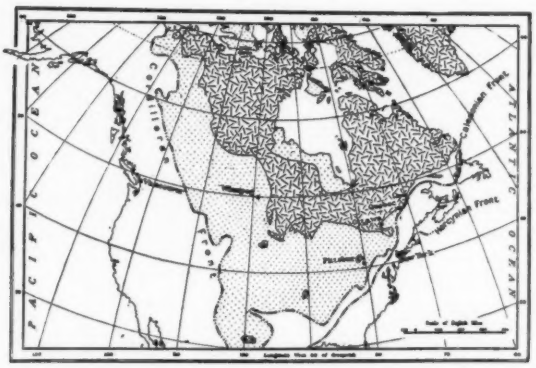

FIG. 1.—Tectonic map of North America. The interior region (Laurentia of Suess) has remained unaffected by mountain folding since pre-Cambrian times. Its pre-Cambrian outcrops are shown by strokes; its Cambrian and later, by stipple. Modified after M. Bertrand (1887), Bailey Willis and G. W. Stose (1911), E. Blackwelder (1912), W. H. Collins (1924), G. A. Young (1926). From E. B. Bailey, "Across Canada with Princeton," *Nature*, Vol. CXX (1927), p. 674.

iniscent of Barrande's Primordial (Middle and Upper Cambrian as understood today). He convinced Logan that a point of prime importance was involved. Accordingly, the locality was carefully searched by the Canadian Survey, and Billings made such headway that on July 12, 1860,[3] he was able to write to Barrande that the Lévis trilobites appeared to be about the base of his (Barrande's)

[1] J. J. Bigsby, "On the Geology of Quebec and Its Vicinity," *Proc. Geol. Soc. London*, Vol. I (1827–28; completed 1834), p. 37.

[2] J. J. Bigsby, *ibid.*, p. 38; and "On the Geology of Quebec and its Environs," *Quart. Jour. Geol. Soc. London*, Vol. IX (1853), pp. 100, 101.

[3] W. E. Logan, "The Geology of Canada," *Mem. Geol. Surv., Canada* (1863–66), p. viii.

second fauna (Ordovician of today). This determination involved momentous consequences, so that here it is necessary to have before us an outline of Canadian Paleozoic geology as understood in the spring of 1860.

Logan had taught for several years that an anticlinal structure, running along the Hudson River, Lake Champlain, and the St. Lawrence, divides Eastern Canada into two dissimilar parts. On the northwest lie flat Paleozoics with the classical stratigraphy of the western portion of New York State, where it had already been admirably worked out by Hall and his colleagues before the foundation of the Canadian Survey in 1843. On the southeast the Paleozoic rocks are of different facies, are highly folded, and are separated from one another by unconformities. Among the southeastern rocks, three great groups concern us at present. They were arranged by Logan in 1855 in the following descending time-sequence:

Southeastern sequence abandoned in 1860	Sillery
	Quebec
	Lorraine

The Lorraine group or formation belongs also to the undisturbed northwestern succession where it is commonly taken as the top of the Ordovician system in the following sequence:

Northwestern sequence	Lorraine
	Utica
	Trenton
	Black River
	Bird's Eye
	Chazy
	Beekmantown (Calciferous)

The 1860 discoveries led Billings to transfer the Quebec group (and by analogy the Sillery) to a basal position in the Ordovician, a veritable revolution in stratigraphy.

A few words may be helpful in connection with Barrande's share in the transaction. The name of this distinguished French *émigré* is today literally written upon the rocks of his adopted country so that all who visit Prague may remember his services to geology. Typical of the man is the paternal interest that he took in securing

recognition for his Primordial fauna in both the Old World and the New. In 1846 he described this fauna as found in Bohemia. It was essentially a peculiar trilobite fauna.[1] In 1851 he was able to point to its occurrence in Scandinavia, England, and Wales, but not in Russia, France, Ireland, or North America.[2] In 1852 he drew attention to the Primordial aspect of two North American fossils represented by casts in European museums.[3] In 1853 he definitely recognized Primordial forms in descriptions from Texas and Wisconsin.[4] It would be out of place to follow every detail, but in 1859 Emmons was able to write regarding certain fossils from the typical Taconic country and from Georgia, Vermont, as follows: "According to Barrande, the *Paradoxides* and *Olenus* belong to his Primordial zone or are sub-Silurian in Bohemia. In this respect our *Paradoxides* are also sub-Silurian: and hence it has been shown that the Primordial zone in Bohemia is in co-ordination with the upper series of the Taconic rocks."[5] Mention of Emmons and his Taconic system recalls to mind one of the most heated controversies of the past. His successes and failures have been variously appraised by his fellow-workers. Barrande has claimed him, overgenerously perhaps, as his one anticipator, who in 1844 already spoke of the fossiliferous portion of the Taconic as constituting the base of the Paleozoic.[6] Walcott, on the other hand, has expressed the opinion that "it is only a fortunate happening, and not a scientific induction based on accurate stratigraphic or palaeontologic work, that any portion of the 'Taconic system' is found to be where Dr. Emmons placed it."[7]

[1] J. Barrande, *Notice préliminaire sur le Système Silurien et les trilobites de Bohême* (Leipzic, 1846), pp. 8–22 (summarized, J. Barrande, "Geologie und Paläontologie des mittleren Böhmens," *Haidinger, Berichte*, Vol. I [1846], p. 162).

[2] "Sur le terrain silurien du centre de la Bohême," *Bull. Geol. Soc. France* (2d ser.), Vol. VIII (1850–51), p. 155; "Sur le terrain silurien de l'Angleterre," *ibid.*, p. 208.

[3] *Système Silurien du centre de la Bohême* (Prague and Paris, 1852), Vol. I, p. 66*d*.

[4] "Silur-Gebilde in Texas und am Oberen See," *Neues Jahrbuch*, 1853, p. 446.

[5] E. Emmons, *Manual of Geology* (Philadelphia, 1859), pp. 87, 280.

[6] J. Barrande, "Documents anciens et nouveaux sur la faune primordiale et le Système Taconique en Amérique," *Bull. Geol. Soc. France* (2d ser.), Vol. XVIII (1860–61), p. 225.

[7] C. D. Walcott, "The Taconic System of Emmons, and the Use of the Name Taconic in Geologic Nomenclature," *Amer. Jour. Sci.* (3d ser.), Vol. XXXV (CXXXV) (1888), p. 395.

While Dana has summed up: "Whether the good or the evil has predominated, we may now hope, while heartily honouring Professor Emmons for his earnest geological labors and his discoveries, that Taconic ideas may be allowed to be and remain part of the past. 1841–1888."[1] Walcott and Dana have certainly advanced strong justification for their judgment in regard to most aspects of the Taconic muddle, but Barrande's share, at any rate, should not be allowed to remain part of the past. Dana was mistaken in describing Barrande as "adopting in his *Memoir* in full the views of Emmons on the Taconic system."[2] As a matter of fact, Barrande in Bohemia anticipated just such a thorough readjustment of the Taconic system as Walcott and Dana later found necessary in their detailed study of the exposures. He showed the utmost discrimination. The beds with Primordial trilobites he hailed with pleasure as Primordial. The graptolites, which Emmons interpreted as older than the trilobites, furnished him with material for four pages of debate.[3] He recalls that "in Europe no graptolite has ever been found older than the Primordial fauna" and that "everywhere these organisms make their first appearance with the second fauna." Accordingly, he suggests that his *savants confrères* may be able to adjust the Taconic evidence in some fashion that will completely restore international harmony.

The story has of course another side. Since 1851 Barrande had maintained his theory of colonies to account for certain Silurian assemblages of graptolites apparently intercalated in the Ordovician of Bohemia.[4] Quite naturally, Hall and Billings thought that a colonial theory could equally well explain an occasional Primordial trilobite found inconveniently placed at the top of the Ordovician in America. The abundant discoveries of 1860 led Billings to reconsider the age of the Lévis beds. The evidence he had to deal with was complicated by the conglomeratic nature of the more important

[1] J. D. Dana, "A Brief History of Taconic Ideas," *ibid.*, Vol. XXXVI (CXXXVI) (1888), p. 427.

[2] *Ibid.*, p. 419.

[3] J. Barrande, *op. cit.* (1860–61), pp. 290–93.

[4] J. Barrande, "Sur le terrain silurien du centre de la Bohême," *Bull. Geol. Soc. France* (2d ser.), Vol. VIII (1850–51), p. 153.

fossiliferous beds. With much judgment and a certain amount of good fortune, he transferred the Lévis rocks to a low position in the Ordovician, where they remain to this day. Let us now consider the tectonic fruits of this stratigraphical reformation. Logan's own words, taken from a letter addressed to Barrande on December 31, 1860, read as follows:

> From the physical structure alone no person would suspect the break that must exist in the neighbourhood of Quebec, and without the evidence of the fossils everyone would be authorized to deny it. If there had been only one or two species of an ancient type, your own doctrine of colonies might have explained the matter, but this I presume would scarcely be applicable to so many identities in a fauna of such an aspect. Since there must be a break, it will not be very difficult to point out its course and its character. The whole Quebec group, from the base of the magnesian conglomerates and their accompanying magnesian shales to the summit of the Sillery sandstones, must have a thickness of perhaps some 5,000 to 7,000 feet. It appears to be a great development of strata about the horizon of the Chazy and the Calciferous [Beekmantown], and it is brought to the surface by an overturn anticlinal fold with a crack and a great dislocation running along the summit, by which the Quebec group is brought to overlap the Hudson River [Lorraine, p. 579] formation. Sometimes it may overlie the overturned Utica formation, and in Vermont points of the overturned Trenton occasionally emerge from beneath the overlap.
>
> A series of such dislocations traverses eastern North America from Alabama to Canada. They have been described by Messrs. Rogers,[1] and by Mr. Safford. The one in question comes upon the boundary of the Province not over a couple of miles from Lake Champlain. From this it proceeds in a gently curving line to Quebec keeping just north of the fortress; thence it coasts the northside of the Island of Orleans, leaving a narrow margin on the island for the Hudson River or Utica formation. From near the east end of the island it keeps under the waters of the St. Lawrence to within eighty miles of the extremity of Gaspé. Here again it leaves a strip of the Hudson River or Utica on the coast.
>
> To the south-east of this line the Quebec group is arranged in long narrow parallel synclinal forms with many overturn dips.[2]

The date combined with the magnitude of this pronouncement seizes upon the imagination. One obvious reflection is that Scotland

[1] It was in 1842 that H. D. and N. B. Rogers gave their brilliant account of "The Physical Structure of the Appalachian Chain" before the Association of American Geologists and Naturalists.—AUTHORS.

[2] "Correspondence of Joachim Barrande, Sir William Logan, and James Hall, on the Taconic System and the age of the Fossils found in the Rock of Northern New England, and the Quebec Group of Rocks," *Amer. Jour. Sci.* (2d ser.), Vol. XXXI (1861), p. 218; W. E. Logan, "The Geology of Canada," *Mem. Geol. Surv., Canada* (1863–66), p. 233.

had to wait for more than twenty years to hear a homologous interpretation of her own northwest Highlands.

In Figures 2 and 3 we reproduce two famous sections, first published by Logan in 1861. Figure 2 gives his interpretation of the great overthrust ("overlap") in its course a few miles east of Quebec. With the minor exception that the rocks on the northwest shore of Orleans Island lie between two branches of the thrust (Fig. 4) instead of under a single thrust (Fig. 2), there is very little to alter. Figure 3 shows his recognition of the trough in which the sediments of the mountain region accumulated. He calculated a slope of nearly 45° for the face of the old pre-Cambrian mass against which the Paleozoic was deposited near Quebec. He added:

FIG. 2.—Logan's section from Montmorenci to Orleans Island. Horizontal and vertical scale, 1 inch to a mile. *g*, Laurentian gneiss; *t*, Trenton limestone; *u*, Utica and Hudson River formations; *q*, Quebec group; *F*, Fault; *O*, Overlap; *S*, Level of the sea. From W. E. Logan, "Considerations Relating to the Quebec Group and the Upper Copper-bearing Rocks of Lake Superior," *Amer. Jour. Science*, 2d series, Vol. XXXIII (1862), p. 321. Logan uses overlap as a synonym for overthrust. The overturned Utica, which he shows below the overlap, is really a thrust-slice of Quebec City formation.

FIG. 3.—Logan's supposed arrangement of the strata before the thrust-break. *T*, Trenton group of limestones; *U*, Utica shales; *H*, Hudson River sandstones and shales; *LL*, Sea-level at the commencement of the Quebec period; *SS*, Sea-level at the close of the Potsdam, and also at the beginning of the Trenton, period. Vertical scale of the section, 1 inch to a mile. From W. E. Logan, *op. cit.*, p. 326. This first illustration of Logan's slope has great historical value, though we depart from it in many particulars.

> Perhaps it would not be extravagant to take this as representing the inclination along the whole line to Alabama. . . . . The solid gneiss in the case before us, offering more resistance than the newer strata, there resulted a break coinciding with the inclined plane at the junction of these with the gneiss. The lower Palaeozoic strata, pushed up this slope, would then raise and fracture the formations above, and be ultimately made to overlap the portion of these resting on the edge of the higher terrace; after probably thrusting over to an inverted dip, the broken edge of the upper formations. . . . . The resistance offered by the buttress of gneiss would not only limit the main disturbance;

but it would probably also guide or modify, in some degree, the whole series of parallel corrugations, and thus act as one of the causes giving a direction to the great Appalachian chain of mountains.[1]

Logan much overestimated the steepness of the face of his long, curved slope, for he did not allow enough horizontal displacement to the rocks carried forward on his overthrust. He also, if we are not mistaken, missed the significance of repeated subsidence at the hinge-line of the slope. Apart from such details, the bold outline of his sketch may be taken as our guide in studying not only American mountains, but also those of other continents. In a sense, Logan's account complements Hall's 1859 insistence upon great thickness of sediments as a characteristic of mountain chains;[2] and we perceive in both cases the confused beginnings of the various geosynclinal theories of later days.

Our present paper continually dwells on the importance of "Logan's slope." We hope to show that, long before it was reached by thrust movements, it served as a limit between different types of sedimentation and also as a *locus* for submarine landslips.

STRATIGRAPHICAL ADVANCES SINCE 1860

It is impossible, owing to considerations of space, to follow *seriatim* the history of Quebec investigation between 1860 and the present day. Among many important contributions, three may be selected for mention. In 1887 Lapworth, as the completely successful opponent of Barrande's colonies in the Old World, was asked by the Canadian Geological Survey to give stratigraphical meaning to the graptolites of the New World. This he did triumphantly, though of course on rather broad lines and with closer reference to British than to American stratigraphical terminology.[3] In 1890 Wal-

[1] W. E. Logan, "Considerations relating to the Quebec Group, and the Upper Copper-bearing Rocks of Lake Superior," *Amer. Jour. Sci.* (2d ser.), Vol. XXXIII (1862), p. 327 (quoted from *Can. Nat. and Geol.*, Vol. VI [1861]); "The Geology of Canada," *Mem. Geol. Surv., Canada* (1863–66), p. 297.

[2] J. Hall, *Geological Survey of New York, Paleontology*, Vol. III (1859), Introduction.

[3] C. Lapworth, "Preliminary Report on some Graptolites from the Lower Paleozoic Rocks on the South Side of the St. Lawrence from Cape Rosier to Tartigo River, from the North Shore of the Island of Orleans, one mile above Cap Rouge, and from the Cove Fields, Quebec," *Trans. Roy. Soc. Canada, for 1886*, Vol. IV, sec. iv (1887), p. 167.

cott distinguished clearly between the fossils of the matrix and the fossils of the boulders contained in the Lévis conglomerates.[1] Barrande had from the first pointed out that the apparent mixture of faunas obtained from these conglomerates was not surprising.[2] Walcott now demonstrated that many of the boulders are faunistically indistinguishable from the matrix in which they lie, while others are of earlier date. In 1914, Raymond published in detail a graptolitic zonal classification of the Lévis shales, which, previously despaired of, had now been achieved in connection with the 1913 meeting of the International Congress.[3] Raymond's work followed naturally upon Ruedemann's zoning of the graptolite shales of Deep Kill, Rensselaer County, New York, published in 1902.

At the present time Logan's Quebec group is split up into the Quebec City and Lévis formations. Raymond in his *Guide* for the 1913 International Congress gives the following stratigraphical table:

		Within the thrust-zone	In front of the thrust-zone
Ordovician	Upper		Lorraine
			Utica
	Middle	Quebec City	Trenton resting on Archean
	Lower	Lévis	
		Sillery	

It is only necessary to abstract a few details from Raymond's account. Among the foreland rocks beginning with the oldest:

The *Trenton formation* is a 500-foot limestone that at Montmorency Falls rests undisturbed on the crystalline Archean. It has four fossil zones traceable through the foreland to central New York.

The *Utica formation* is a 200-foot dark shale—*Climacograptus typicalis* and *C. bicornis* common.

The *Lorraine formation* is a 700-foot (at least) fine, soft, gray

[1] C. D. Walcott, "A Review of Dr. R. W. Ell's Second Report on the Geology of a Portion of the Province of Quebec; with additional Notes on the 'Quebec Group,'" *Amer. Jour. Sci.* (3d ser.), Vol. XXXIX (CXXXIX) (1890), p. 111.

[2] Barrande, *op. cit.* (1860–61), pp. 214–15.

[3] P. E. Raymond, "The Succession of Faunas at Lévis, P.Q.," *Amer. Jour. Sci.* (4th ser.), Vol. XXXVIII (CLXXXVIII) (1914), p. 523.

micaceous shale with a few round-grained sandstone beds—*Diplograptus pristis* common.

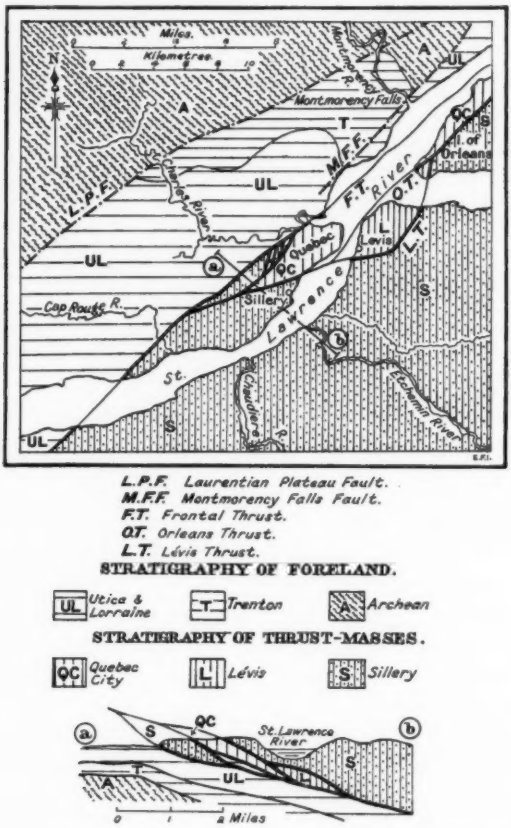

FIG. 4.—Diagrammatic map and section of Quebec and neighborhood

Among the thrust rocks beginning with the oldest:

The *Sillery formation* consists of a great thickness of red and green sandstone with, also, beds of limestone conglomerate. Some think, and probably no one denies, that the Sillery may be largely Cambrian. Much of it is unfossiliferous. Parts yield only the little

inarticulate brachiopod *Acrothele pretiosa*. Other parts furnish an admixture of this form with Lévis graptolites, although *A. pretiosa* does not occur in typical Lévis exposures. Unless this admixture of forms is due to inadvertent collection from intercalated thrust slices, there is no doubt that a portion of the Sillery is Ordovician. Clark, in discussing the evidence, thinks that it points to the Sillery as the downward continuation of the Lévis.[1] The fossiliferous limestone boulders in the Sillery conglomerates are exclusively Cambrian; almost all of them are of Lower Cambrian date, but an occasional example, Raymond says, belongs to the Upper division.[2]

The *Lévis formation* consists mostly of hard gray, green, and red shale, thin-bedded hard blue and light-gray limestone, and thick and thin beds of limestone conglomerate—total exposure about 1000 feet. In 600 feet of these rocks, Raymond distinguished four main graptolite zones, each with subdivisions. Clark thinks that additional collecting makes it safer to reduce the main zones to three by uniting the two middle members as follows in descending order:[3]

	Feet
Diplograptus dentatus zone	225
Tetragraptus-Didymograptus zone	310
Clonograptus zone	50?

The fossiliferous limestone boulders of the conglomerates include a few of Lower Cambrian and a profusion of Upper Cambrian and Beekmantown date. The matrix of the conglomerates contains fossils with thick shells also of Beekmantown date (and facies). Pebbles other than limestone are comparatively rare, but Raymond has identified gneiss, igneous rocks, quartzites, and Sillery shales and sandstones.[4] We have ourselves recognized Lévis shales in one exposure (p. 600).

[1] T. H. Clark, "The Paleontology of the Beekmantown Series at Lévis, Quebec," *Bull. Amer. Paleont.*, Vol. X, No. 41 (1924), p. 43.

[2] What constitutes Upper Cambrian is a very moot point. Raymond speaks of "Upper Cambrian or Lower Ordovician ('Tremadoc' or 'Ozarkian')" (P. E. Raymond, "Quebec and Vicinity," *Guide Book No. 1, Internat. Geol. Congress* [issued Geol. Surv. Canada, 1913], p. 30). In this paper we use "Upper Cambrian" for rocks younger than Paradoxidian and older than Arenignician. It is interesting to note that Ulrich reports that one of the Lévis boulders carries Atlantic Lower Ozarkian, but most of the boulder fauna indicates Upper Ozarkian of the American (Cordilleran) type.

[3] *Op. cit.*, p. 56.

[4] *Op. cit.*, pp. 30, 39.

The *Quebec City formation* consists of a great thickness of hard, fine-grained limestone, very dark shale, and thick and thin beds of limestone conglomerate. The graptolite fauna of the shales, including *Corynoides calycularis*, etc., indicates a mid-Trenton age. The fossils of the limestone boulders are of Black River and Lower Trenton age, though not of the same character as the fossils found in Canada in these formations northeast of the Champlain–St. Lawrence thrust.

The detailed consideration of the conglomerates that have been mentioned as occurring in all three divisions of the thrust-zone is best deferred until after a short account of the tectonics of the district.

STRUCTURE

Figure 4 represents in diagrammatic fashion some of the main structural features of the neighborhood of Quebec.

An important normal fault, named by Kindle and Burling the *Laurentian Plateau fault*,[1] serves as southeastern boundary of the principal exposures of Laurentian gneiss near Quebec. It continues southwestward for more than two hundred miles to Ottawa and then, as the authors quoted have shown, bends northwestward. Between Quebec and Montreal, the Plateau fault runs roughly parallel with the St. Lawrence thrust-zone, but beyond that town the two structures diverge very widely. The throw of the Plateau fault is probably some thousands of feet.

The *Montmorency Falls fault* was very early recognized. It is a normal fault with a 600-foot downthrow. Northwest of the fault, at the top of the Montmorency Falls, the Trenton limestone lies almost horizontally on the Archean; whereas, on the other side, the downthrown Utica and Lorraine shales dip southeastward at about 40° (Fig. 2).

Logan's line, as the St. Lawrence thrust-zone is often called, has become increasingly complex with continued research. This tendency is clearly shown in the map that Raymond gives in the 1913 *Guide*, and to a further extent in our own diagram (Fig. 4).

[1] E. M. Kindle and L. D. Burling, "Structural Relations of the Pre-Cambrian and Palaeozoic Rocks North of the Ottawa and St. Lawrence Valleys," *Canada Geol. Surv. Museum Bull.*, No. 18 (1915), Fig. 5.

As one element in "Logan's line," we have mapped a *frontal thrust* in the north channel of the St. Lawrence betweeen the mainland and the Isle of Orleans, and thence southwestward far beyond Quebec. Its presence is shown by the following facts:

1. In front—that is, northwest—of the thrust lie Upper Ordovician shales dipping toward the southeast.

2. Southeast of the thrust line are important outcrops of much disturbed Middle Ordovician rocks in the Isle of Orleans and Quebec, and of Lower Ordovician or Cambrian rocks on the mainland southwest of Quebec.

3. The Middle Ordovician rocks southeast of the thrust are of Quebec City facies and differ profoundly in lithology and fauna from the contemporary Trenton limestone that underlies the Utica shales northwest of the thrust. Raymond says that, in New York State, strata with Quebec City fauna occur nearly fifty miles east of the nearest outcrop that contains a Trenton limestone fauna such as is found at Montmorency Falls—though, he adds, "The thrust need not necessarily have been so much as that."[1]

4. The Lower Ordovician or Upper Cambrian (Sillery formation), southeast of the thrust, belongs to an age unrepresented in the rock sequence locally found northwest of the thrust.

5. For some distance, a series of superimposed thrust slices is visible in a northwest-facing cliff that runs through Quebec.

This last point is the only one in which we have advanced upon Raymond's position. Raymond thought that a cross-fault in some way terminated the Quebec City outcrop to introduce the Sillery formation on the southwest—both formations resting upon the frontal thrust. We thoroughly agree with the last part of this proposition, but not with the cross-fault. We find that the Quebec City formation passes over the Sillery with an intervening zone of thrust slices that consist of the Lorraine and Sillery formations. Here we should like to say that the only new identification involved in our interpretation of the structure is that of a slice of Sillery formation intercalated among the Lorraine shales (Fig. 5). Its material seems identical with the brittle Sillery shale found in mass farther southwest.

[1] *Op. cit.*, p. 27.

The following local details will enable anyone to follow our interpretation on the ground:

Arago Street runs along the foot of the bluff and serves as a base of attack.

The Quebec City formation occupies the bluff southwest to beyond Côte Badelard (Côte de la Négresse in Raymond's *Guide*). The cliff is then obscure for a bit, but is soon occupied, under the Martello Tower, by Lorraine shales. Raymond has given good reason to believe that the Quebec City formation here overlies the Lorraine shales with conformable dip—a thrust contact.

Raymond thought that the Lorraine shales continued from the Martello Tower southwest all along the cliff to a ladder leading up from Victoria Street. There is, however, a very considerable intercalation of Sillery-shale type at the hill road that leads up from De

FIG. 5.—Diagrammatic section drawn, not to scale, along northwest bluff of Quebec City. The names, except Martello Tower, are formational. The division lines are thrusts.

Mazenod Street, and we are confident that it is a thrust slice separating the Lorraine outcrop into two.

The steps from Victoria Street connect with a hill road, called, by Raymond, Reservoir Hill (its continuation across Arago Street is Aqueduct Street). The steps start on Sillery shale below the bottom slice of Lorraine shale, and reach up to the latter near an exposure that has yielded Raymond an abundance of graptolites. Raymond thought that this fossiliferous Lorraine was in faulted contact with Sillery farther down Reservoir Hill.[1] This is not correct, for the Lorraine really overlies the Sillery and is seen definitely in this position at the top of a cliff southwest of Reservoir Hill. There can be no doubt that their contact is a thrust.

So far as is known, the Sillery occupies the bluff southwestward of this point continuously to the St. Lawrence. It must be thrust over the Lorraine shales of the low ground to the northwest.

The *Orleans thrust*, according to Raymond, brings Sillery and

[1] *Ibid.*, p. 46.

Lévis shales on to the top of the city of Quebec formation in the Island of Orleans. It is there part of the original "Logan line," though on the mainland, in Quebec City and to the southwest, Logan drew his line where we now map the frontal thrust. The Orleans thrust is continued by Raymond up the St. Lawrence past Quebec and Sillery. Appearances, however, very strongly suggest that the Orleans thrust comes ashore on the north side of the St. Lawrence at Wolfe's Cove, where a road today leads up the coastal cliff. The Quebec and Sillery formations agree in having steep southeasterly dip, and there is an apparent upward succession from Quebec to Sillery, as in much of the Isle of Orleans. Raymond thought that the southwestward replacement of Quebec City formation by Sillery observed in this coastal cliff was due to the same fault as he had invoked in his interpretation of the inland bluff that follows the frontal thrust.[1] We could, however, find no evidence of this supposed fault in the coastal cliff, and it will be remembered that we have disproved its existence in the inland bluff—but, as will readily be understood, our correction, even if justified, affects only a matter of detail.

Exposures are poor between the coastal and inland bluffs, and the termination southwestward of the Quebec City outcrop is merely diagrammatically suggested in Figure 4, where the formation is drawn as wedging out between overlying and underlying Sillery shales.

The *Lévis thrust* of Figure 4 may not be continuous, but we think that it probably is. The evidence is as follows:

On the mainland, the junction of the Lévis and Sillery formations is only exposed at one point, namely, in the seacliff south of Lévis town. Raymond has drawn a "fault" at this place, at the same time recording a pronounced change of strike.[2] Clark describes this "fault" as traversing the cliff in an almost vertical line with accompanying remarkable contortion.[3] The dislocation, whether we call it a fault or a thrust, must run inland for a mile and a half in a general easterly direction. Beyond this, the boundary be-

[1] *Ibid.*, pp. 35, 46.

[2] *Ibid.*, p. 36.

[3] T. H. Clark, "The Structure of the Lévis Formation at Lévis, Quebec," *Trans. Roy. Soc. Canada* (3d ser.), Vol. XX, sec. iv (1926), pp. 178, 179.

tween the two formations turns northeast. At first it separates the upper part of the Lévis formation from the Sillery, and is regarded by Clark as probably a thrust. Farther on, pitch brings up lower members of the Lévis formation, and Clark thinks that these may make conformable contact with the Sillery.[1] Against this view it may be urged that farther north still, in the Isle of Orleans, the junction is admittedly a thrust bringing Sillery formation over Lévis.

The sketch we have given is necessarily only broad and general. Various cross-faults and a thrust have been recognized within the Lévis outcrop, but readers can turn to Raymond and Clark for details regarding them. It is enough for our purpose to realize that Quebec and its neighborhood furnish *clear evidence of large-scale thrusting involving the transport of sedimentary formations from one province of deposition into another.*

SUBMARINE LANDSLIP CONGLOMERATES

The conglomerates, to which we now turn, have many remarkable features.

Distribution.—Logan has described conglomerates of the Quebec type on the west coast of Newfoundland and at several points on the south shore of the St. Lawrence. Other investigators have drawn attention to similar accumulations in Vermont, New York, Pennsylvania, and Virginia, and, if we include late pre-Cambrian examples, in Tennessee. Many of these conglomerates have been cited by Walcott in his *Paleozoic Intra-formational Conglomerates* published in 1894. The Quebec conglomerate facies follows approximately the same line as Logan's pre-conglomerate slope and post-conglomerate thrusting.

Recurrence.—Frequent repetition of conglomerate conditions through a prolonged period is a characteristic of several of the localities mentioned above. Near Quebec, for instance, conglomerate conditions are met with in the Sillery, Lévis, and Quebec City formations. In a measured 422 feet of the Lévis formation, Raymond lists five beds of conglomerate, the thickest measuring 12 feet and the thinnest 4 inches.[2] Logan thought that at least nine conglom-

[1] *Ibid.*, p. 180.

[2] P. E. Raymond, "The Succession of Faunas at Lévis, P.Q.," *Amer. Jour. Sci.* (4th ser.), Vol. XXXVIII (CLXXXVIII) (1914), p. 524.

erates could be distinguished in the Lévis formation taken as a whole,[1] and his results have been confirmed by later observers. The

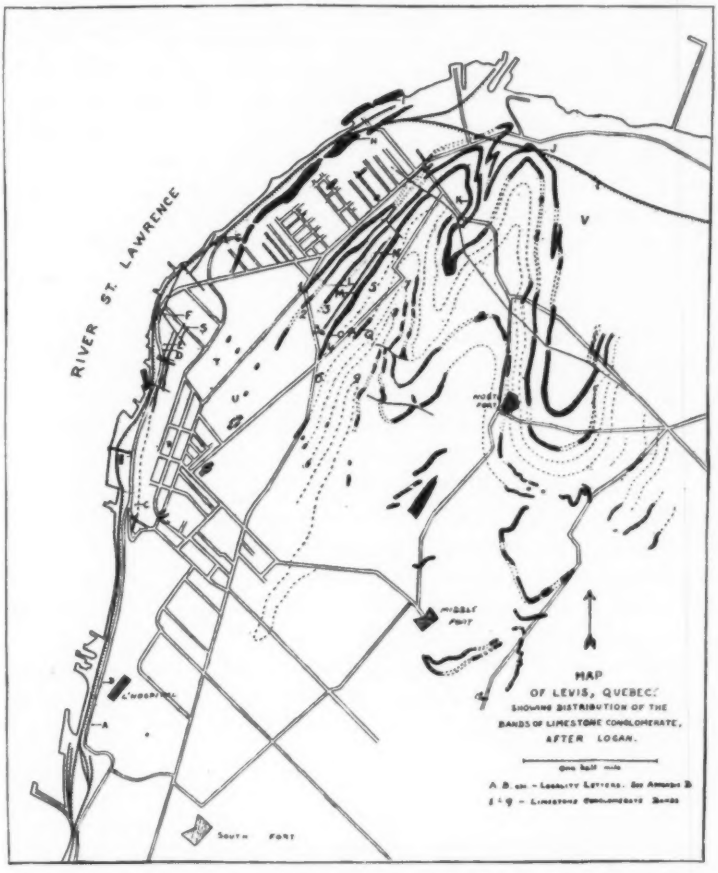

FIG. 6.—Map of Lévis conglomerates. From T. H. Clark, "The Paleontology of the Beekmantown Series at Lévis, Quebec," *Bull. Amer. Paleont.*, Vol. X (1924), Plate I.

recurrence of conglomerate conditions is further emphasized by rather numerous instances of conglomerate boulders inclosed in

[1] W. E. Logan, "The Geology of Canada," *Mem. Geol. Surv., Canada* (1863–66), p. 860.

conglomerate matrix. It must be remembered that the Quebec conglomerates consist essentially of limestone and have therefore been liable to rapid cementation.

Not indications of wide unconformities.—It is clear that the recurrent conglomerates of the Quebec district do not represent wide unconformities. The Lévis graptolitic shales, for instance, among which some of them are interstratified, have been minutely zoned, and the interstratified conglomerates have been demonstrated to mark mere episodes, not breaks, in the succession.

Pene-contemporaneous boulders.—The conglomerates of the Quebec district have derived much of their material from limestones very little older than themselves. Often, in other conglomeratic sequences, older and older pebbles are met with as one examines successively younger layers of conglomerate; but at Quebec exactly the opposite relation obtains. Let us take the evidence *seriatim*.

The conglomerates of the Sillery formation include abundant Lower Cambrian (*Olenellus*) boulders.[1] Raymond says "an occasional specimen has been found which indicates the *Dikelocephalus* fauna" of the Upper Cambrian.[2] Clark says: "There are no other fossiliferous boulders" than Lower Cambrian.[3]

The Lévis conglomerates, according to Clark, carry a few Lower Cambrian boulders and many of Upper Cambrian and Beekmantown age;[4] and Walcott has found that the proportion of old pebbles decreases rapidly as the sequence is ascended:

> The Lower bed of limestone conglomerate at Point Lévis occurs near the base of the Ordovician, in the Point Lévis shale. It is made up of large and small boulders of limestone, carrrying the Upper Cambrian fauna, that are embedded in the limestone matrix in which occurs the typical Calciferous [Beekmantown] fauna. . . . . The matrix of the conglomerate proves the formation to be of Lower Ordovician age. In a bed of limestone fifty feet higher up in the section I found additional species of the Calciferous fauna, and in a bed of limestone conglomerate above this the fossils in the boulders and in the matrix

[1] C. D. Walcott, "Paleozoic Intra-formational Conglomerates," *Bull. Geol. Soc. Amer.*, Vol. V (1894), p. 193.

[2] P. E. Raymond, "Quebec and Vicinity," *Guide Book No. 1, Internat. Geol. Congress* (issued Geol. Surv. Canada, 1913), p. 31.

[3] T. H. Clark, "The Paleontology of the Beekmantown Series at Lévis, Quebec," *Bull. Amer. Paleont.*, Vol. X, No. 41 (1924), p. 4.

[4] *Ibid.*, p. 3.

as well are of Calciferous age. In a search of two days I failed to find a Cambrian fossil. . . . . This second band of conglomerate in the Lévis series appears to be a true intraformational conglomerate.[1]

Intraformational conglomerate is defined by Walcott as "one formed within a geologic formation of material derived from and deposited within that formation,"[2] where formation means a "unit of geologic nomenclature . . . . as lithologically defined"[3]—not a "number of groups or stages" as it does in Archibald Geikie's *Text Book*.

The Quebec City conglomerates do not seem to include Cambrian or Beekmantown boulders, but instead are full of Black River and Lower Trenton representatives.[4]

Disorderly arrangement.—The conglomerates of the Quebec group as a whole are of irregular distribution and vary rapidly in thickness.[5] Among Lévis examples exposed by the roadside near *D* (Fig. 6), a 15-foot layer dwindles to 2 feet within quite a short distance.[6] Those that we have examined at this locality show no indication of bedding (Fig. 8) beyond the fact that a layer of small débris furnishes a smooth top to each accumulation. Limestone boulders over a foot in diameter are common. Smaller pebbles of similar material are fitted in between. Boulders and pebbles alike often have worn angles, but are far from rounded. The whole is set in a rusty weathering limestone matrix charged with round quartz grains (wind-worn originally). These grains have resulted, in part at least, from the breaking-down of sandstone, for round-grained sandstone occurs fairly frequently as pebbles in the conglomerate. Below one of the conglomerate beds exposed at the roadside, two

[1] C. D. Walcott, "Paleozoic Intra-formational Conglomerates," *Bull. Geol. Soc. Amer.*, Vol. V (1894), p. 193.

[2] *Ibid.*, p. 192.

[3] C. D. Walcott, "The Taconic System of Emmons, and the Use of the Name Taconic in Geologic Nomenclature," *Amer. Jour. Sci.* (3d ser.), Vol. XXXV (CXXXV) (1888), p. 229.

[4] P. E. Raymond, "Quebec and Vicinity," *Guide Book No. 1, Internat. Geol. Congress* (issued Geol. Surv. Canada, 1913), p. 29.

[5] J. W. Dawson, "On the Eozoic and Palaeozoic Rocks of the Atlantic Coast of Canada, in Comparison of those of Western Europe and the Interior of America," *Quart. Jour. Geol. Soc. London*, Vol. XLIV (1888), p. 809.

[6] Raymond, *op. cit.*, p. 38.

limestone boulders lie totally immersed in shale (they show poorly in Fig. 8). The bedding of the shale bends conspicuously down to

FIG. 7.—Sixty-foot limestone boulder in conglomerate. The latter shows at left end of quarry. Locality M of Figure 6.

FIG. 8.—Conglomerate interbedded in shale. Locality D of Figure 6

pass under the boulders and less conspicuously up to pass over them. Merely a film of shale separates the blocks from the overlying conglomerates, and it looks as though these boulders had traveled in

advance of their fellows along the sea bottom, and then had been overtaken and pushed down into the mud.

The general disorderly arrangement of the Lévis conglomerates immediately suggests a subterranean tectonic origin. No one, however, has been misled by appearances into interpreting these rocks as crush conglomerates, for their material and fossils cannot be matched in the series among which they lie interbedded. Even the subordinate limestone intercalations of the Lévis shale are quite different in type from the limestone boulders; and the merest tyro can realize that the sand grains of the conglomerate matrix are absent from the intervening rocks.

Of the Quebec City conglomerates, we studied only one exposure, that of Côte de la Montagne, already discussed and illustrated by Raymond.[1] It is not altogether possible in this case to distinguish between movements posterior to the conglomerate and others that attended its formation. The boulders and pebbles are mostly limestone of various types, including oölitic and gritty varieties. The heterogeneity of the boulders is well illustrated in our photograph (Fig. 9). A geologist is seen standing beside a prominent block of compact limestone which at once attracts attention. Immediately to the right of the block is an equally big mass consisting of interbedded gray shale and limestone layers with undulating bedding. It is quite possible that this boulder has hitherto escaped attention, for at first sight it looks like a matrix rock rather than an inclosure. Careful examination, however, shows that the two boulders are separated from one another by an almost vertical film of round-grained sandstone. Moreover, to the left, the outstanding boulder is bounded along both sides of its subrectangular outline by black homogeneous shale.

This Côte de la Montagne exposure will repay more than the few hours that we have been able to devote to it. Our photograph does not include nearly the whole of the conglomerate of the cliff face, and in this respect may usefully be supplemented by Raymond's illustration.[2] It is probable that more than one conglomeratic episode is recorded. Figure 9 shows a band of black shale, practically free of pebbles, descending the cliff from right to left

[1] *Ibid.*, pp. 43, 45.

[2] *Ibid.*, p. 45.

about the middle of the picture. The shale has developed a slaty cleavage, and this renders the recognition of bedding in many cases

FIG. 9.—Conglomerate in Quebec City formation, Côte de la Montagne, Quebec City.

a matter of uncertainty, though very occasionally contorted bedding can be distinguished crossed by the cleavage.

Gigantic boulders.—Figure 9 illustrates the fact that some of the Quebec boulders are about ten feet in diameter. Three exception-

ally large masses associated with conglomerate outcrops near Lévis are, however, generally regarded as relics of limestone beds *in situ*.[1] They occur at localities lettered *K*, *L*, and *M* on Figure 6, which we reproduce from Clark's description.[2] To two of them, *L* and *M*, we had the great good fortune of being conducted by Clark himself. We followed up this invaluable introduction by returning next day and devoting ourselves to particular aspects of what is certainly a bewildering problem. Raymond and Clark's descriptions indicate that these limestone masses are approximately contemporaneous with the shales among which they, along with their attendant conglomerate, are interbedded. Our own observations are given below.

Locality L.—With Clark's map, a visitor should have no difficulty in locating this "low white limestone outcrop in pasture about fifty feet across, just south of path." The exposure is not suitable for full examination of the surrounding rocks, but it shows quite clearly that the 50-foot outcrop of solid limestone partially interrupts a conglomerate band of the ordinary Lévis character. The white surface of the limestone mass is varied by irregularly shaped pale-rusty areas of gritty limestone of the same type as supplies the matrix of the adjacent conglomerate. It contains conspicuous thick-walled fossils, for instance, chambered cephalopods, the cavities of which it completely chokes. Apparently the white limestone, at some date prior to the formation of the associated conglomerate, was exposed to the atmosphere and perforated with solution pipes, now blocked with shells and calcareous grit. We merely record this observation as of interest in itself. It does not answer the question as to whether the limestone is *in situ* or transported. Another item of evidence does, however, suggest special conditions attending the formation of the conglomerate. A narrow crevice can be traced across part of the limestone face. It has approximately the same attitude as the shales that flank the conglomerate band, and therefore it must have been approximately horizontal before these shales were turned upward. It is traceable for about ten feet, and for most of its course it measures only a minute fraction of an inch in cross-

[1] *Ibid.*, p. 47.

[2] T. H. Clark, "The Paleontology of the Beekmantown Series at Lévis, Quebec," *Bull. Amer. Paleont.*, Vol. X, No. 41 (1924), Plate I, pp. 37, 101.

section. With these dimensions it is surprising to find it everywhere packed with the same type of gritty limestone that has been described above. The usual rounded quartz grains are present, and in diameter they are often nearly as large as the gape of the long crevice that they line. It looks as though a gritty calcareous mud had been powerfully injected into every available opening.

Locality M.—A quarry on what is called the North Ridge makes quite a conspicuous landmark to the east of locality *L* (Figs. 6 and 7). It is opened in a limestone mass some 60 feet long, measured with the strike of the adjacent shales, and 35 feet high at right angles to their dip. The shales are inclined steeply southeast, and there is good fossil evidence for regarding their attitude as uninverted.[1] We can therefore distinguish between the original base and top of the exposure. Along its bottom, the limestone rests concordantly on shale. At its top, it is covered in most irregular fashion by characteristic Lévis conglomerate, with a recognizable proportion of Upper Cambrian boulders.[2] At its two exposed sides, for more than half its height, the limestone is similarly bounded by conglomerate; but below this level it projects from 10 to 15 feet into the underlying shales. At the right-hand limit of the quarry, there is great contortion of the shales bordering the lower portion of the limestone face. Such contortion is suggestive of the limestone mass sliding forward and plowing into plastic muds. It might, however, be attributed to subsequent complications, attendant upon consolidation or tectonics. Fortunately, more ample exposures at the left end of the quarry prove beyond doubt that the Lévis shales were splattered about at the time of formation of the conglomerate. Great flakes of these shales, a few inches thick and a couple of feet in diameter, lie higgledy-piggledy among the limestone boulders. They are bent and twisted and sometimes rived out into fingers. Their form in itself conveys a feeling of bodily slipping movement of the inclosing conglomerate.

The appearances at exposure *M* seem to us decisive in favor of a submarine landslip interpretation. This view has another great advantage, for as soon as the masses at exposures *K*, *L*, and M are

[1] T. H. Clark, "The Structure of the Lévis Formation at Lévis, Quebec," *Trans. Roy. Soc. Canada* (3rd ser.), Vol. XX, sec. iv (1926), p. 171.

[2] Raymond, *op. cit.*, p. 47.

interpreted as landslip boulders, they take their place quite naturally as the largest of millions of variously dimensioned landslip boulders in their vicinity. On the other hand, so long as these masses are interpreted as relics left *in situ* of once widely extending beds, then they stand by themselves, and the fact that they only measure 50 or 60 feet in length becomes a strange coincidence.

Gigantic boulders have already been recognized in a representative of the Quebec conglomerates near Lake Champlain, just south of the Canadian border. The conglomerate in this case is supposed by Keith to be of Middle Ordovician age, and it contains boulders up to 60 feet in length, or perhaps, as suggested by Sayles, up to 170 feet.[1]

Source of boulders.—Most of the boulders in the conglomerates in the vicinity of Quebec cannot be matched in local outcrops. Let us first consider the boulders characteristic of the Sillery and Lévis conglomerates.

> There are no outcrops of limestone containing the *Olenellus* fauna nearer than Labrador, 500 miles (800 km.) northeast of Lévis; the nearest outcrop containing the *Dikellocephalus* fauna is at Whitehall, N.Y., 250 miles (400 km.) southwest; and the nearest outcrop of fossiliferous Beekmantown is at Bedford, Quebec, 150 miles (240 km.) southwest of Lévis. Yet the vast numbers and often large size of the pebbles in the conglomerates indicate that the older limestones outcropped near the basin where the Lévis shales were formed, and it seems very probable that such beds now exist somewhere to the southeast of Lévis, entirely buried by the shales which have been thrust over them.[2]

With this conclusion of Raymond's we entirely agree. Beekmantown limestone (Calciferous) is of American facies, that is, of the facies proper to the great interior region of North America, northwest of the Atlantic mountain belt. It is unrepresented at Montmorency Falls, merely because this part of Canada stood above sea-level in Beekmantown times. On entering the mountain belt, southeast of Montmorency, one passes, in imagination, down the face of Logan's slope to reach an area that was submerged in Beekmantown times (and also in Upper and Lower Cambrian times). That Beekmantown limestone of typical American facies was deposited

[1] A. Keith, "Cambrian Succession of Northwestern Vermont," *Amer. Jour. Sci.* (5th ser.), Vol. V (CCV) (1923), pp. 116, 119, 134.

[2] Raymond, *op. cit.*, p. 30.

in some part of these southeastern seas is attested by the boulders of the Lévis conglomerate; and we may fairly confidently assume, from experience gathered along the mountain front as a whole, that its depositional zone lay northwest of that of the contemporaneous Lévis shales, since these latter are of typical Atlantic facies. Accordingly, we must suppose that the Lévis shales have been thrust over Beekmantown limestone to reach their present situation.

The evidence of the Quebec City conglomerates is not so straightforward. Their boulders, apparently, are all of Atlantic facies, and might possibly, so far as character goes, have been derived from the southeast just as easily as from the northwest. Fortunately, however, a Trenton conglomerate of the same suite, but occurring farther south at Rysedorph Hill, Rensselaer County, New York, has furnished more helpful information. It has been minutely studied by Ruedemann, who has found that its most abundant fossiliferous pebbles consist of gray (American) and black (Atlantic) Trenton limestones. The former he considers slightly the older of the two types. The latter contains, among others, three species which, named for the first time by Ruedemann,[1] have later been listed by Raymond from the Quebec City conglomerate as "unknown in the typical Trenton."[2] The admixture of American with Atlantic facies among the Rysedorph pebbles carries with it a distinct though rather weak suggestion that the pebbles have traveled from the west. We adopt this conclusion, essentially because we feel that the whole series of conglomerates Sillery, Lévis, and Quebec City (with Rysedorph) are due to recurrence of similar geographical conditions —and we are prepared to interpret these conditions in the light of the very suggestive evidence furnished by the Lévis conglomerates.

Ruedemann, however, has read the Rysedorph formation in exactly the opposite sense. He is especially impressed by the Atlantic facies of so many of its contained pebbles of Trenton age and is certain that their source must lie east of the conglomerate outcrop.[3] We agree that this is the position of affairs at the present day, but we remember the conception that Raymond has developed in rela-

[1] R. Ruedemann, "Trenton Conglomerate of Rysedorph Hill, Rensselaer Co., N.Y., and its Fauna," *New York State Museum, Ann. Rep. 55* (1903, for 1901), pp. 19, 46, 48.

[2] *Op. cit.*, p. 29.

[3] *Op. cit.*, pp. 107, 108, 114.

tion to the Lévis conglomerates, and we claim that the original geographical relationship of conglomerate and source has been reversed by thrusting.

Our interpretation.—We interpret the conglomerates of the Quebec district as submarine formations because they are interbedded among fossiliferous marine shales. We interpret them as landslips because: (1) Through a succession of geological ages they repeatedly recur along a particular tectonic zone. (2) A large proportion of their boulders are pene-contemporaneous. (3) Their internal arrangement is tumultuous and unbedded. (4) Some of their boulders are gigantic—certainly 60 feet long—and can be shown to have plowed into the underlying shale. (5) Their material has apparently moved to some extent *en masse*. (6) There is evidence of forcible injection of their scanty matrix into cracks. (7) It seems impossible to consider them as glacial—this last point will be treated presently under the head of "Earlier Interpretations," where it will also be shown that our thesis is not altogether a novelty.

Our conception of recurrent conglomerate formation along the course of the Logan slope is very simple. We suggest that the slope was renewed by intermittent hinged subsidence, in part of monoclinal, and in part of block-fault type. The tilting and faulting exhibited at Montmorency Falls presents us with a suggestive picture of the tectonic conditions. Many modern submarine slopes are the site of tremendous earthquake shocks.[1] It needs little imagination to conjure up repeated earthquakes as incidental to the maintenance of Logan's slope through much of early Palaeozoic time. Sublacustrine landslips have been closely studied in connection with the Swiss lakes, and one that carried away twenty houses and traveled for a kilometer was precipitated by the driving of piles.[2] Chaos must reign upon any steep submarine slope subjected to a first-class earthquake. The upper part of Logan's slope we picture as clothed in limestones, predominantly of American facies. The lower part in muds, fed through the waste of mountain land to the east. Landslips are recorded in the débris of the resistant limestones

[1] Kendall's insistence upon the importance of earthquakes in geology is well known to British students (P. F. Kendall and H. E. Wroot, *Geology of Yorkshire* [Vienna, 1924], chap. xviii).

[2] L. W. Collet, *Les Lacs* (Paris, 1925), p. 195.

showered down upon the muds. If the limestones had not consolidated almost contemporaneously with their formation, their débris would have been mere shelly ooze, and the story of the landslips might well have been illegible.

It will be realized that our landslip conception affects the rôle attributable to the matrix fossils of the conglomerates. These fossils represent unconsolidated bottom accumulations belonging to the limestone belt that fed the conglomerates. In so far as the organisms were still alive when any particular landslip occurred, we may describe them as having died, rather than lived, during the formation of the resultant conglomerate. It will be readily appreciated that this view renders intelligible the finding of exactly similar fossils in matrix and pebbles alike.

Field reports[1] that large blocks of oölitic limestone are being detached by the waves from the cays which fringe the Great Bahama and Little Bahama banks. These blocks are being deposited on the extremely steep slope which faces the Santaren Channel and the Gulf Stream. The submarine slope, in places, descends over 500 fathoms in from $\frac{1}{8}$ to $\frac{1}{4}$ mile from shore. It is quite probable that the slope is fairly rugged, or broken by scarps or submarine cliffs. The blocks of oölite contain the same fauna as the oozes in the lagoon behind the cays, and some of the oozes also contain "oöliths" which have been weathered from the cays on the lagoon side. The sediment from the lagoon is being washed out between the cays and deposited on the steep submarine slopes to form the matrix of the pene-contemporaneous conglomerates. If the muds from the Mississippi Delta extended to the southeast so as to lie upon the deeper portion of the submarine slope there would be a condition of facies very similar to that of the Lévis conglomerates; or if the Bahama horst had had a cover of unconsolidated, relatively unfossiliferous Cretaceous clays, these might have been washed down the submarine slope and deposited as a reworked matrix facies with a fauna largely contemporaneous with the large blocks or breccia derived from the later cay rock.

Earlier interpretations.—Every observer has recognized that the conglomerates so commonly found along Logan's line are in some

[1] R. M. Field, "The Great Bahama Bank," *Amer. Jour. Sci.*, September, 1928, p. 242.

sense submarine. Logan himself treated them as a product of the submergence of his steep slope, and suspected oscillation.[1] L. W. Bailey and W. McInness have thought of them as shore deposits and attributed transport of their material to rivers.[2] Ruedemann has invoked wave action accompanying strong tidal or coastal currents.[3]

The foregoing explanations do not seem sufficient to account for the disorderly unbedded character that we have observed at Quebec, or for the gigantic size of some of the boulders, or for the evidence of plow action at the base of such boulders, or for the injection of the particular matrix into cracks. These difficulties are to some extent self-evident. In 1883 they led Dawson to express the view that "only the conjoined action of Arctic current bearing mud and ice and of the earthquake waves connected with the igneous action proceeding at the time to the southward, can account for such a formation."[4] The "huge earthquake waves," he claimed, "tore up the rocks of the sea bottoms and coasts, and formed great irregular beds of conglomerate, sometimes with boulders many feet in length." Dawson's earthquake waves may be considered the prototypes of our own, though they were presently abandoned by their author in favor of ice-floes.

In 1888 Dawson expressed the view that "the only means of explaining these conglomerates seems to be the action of the coast ice, which at this period appears to have been as energetic on the American shores as at the present day, and seems to have had great reefs of limestone . . . . to act upon."[5] Glacial assistance has also been called in by various later authors. Walcott has admitted that

[1] W. E. Logan, "Considerations relating to the Quebec Group, and the Upper Copper-bearing Rocks of Lake Superior," *Amer. Jour. Sci.* (2d ser.), Vol. XXXIII (1862), p. 325 (quoted from *Can. Nat. and Geol.*, Vol. VI [1861]); W. E. Logan, "The Geology of Canada," *Mem. Geol. Surv., Canada* (1863–66), p. 294.

[2] "Report on Portions of the Province of Quebec," *Ann. Rep. Geol. Surv., Canada, for 1890–91*, Vol. V, Part I (1893), p. 25M.

[3] R. Ruedemann, "Trenton Conglomerate of Rysedorph Hill, Rensselaer Co., N.Y., and its Fauna," *New York State Museum, Amer. Rep. 55* (1903, or 1901), p. 110.

[4] J. W. Dawson in B. N. Harrington's *Life of Sir William E. Logan* (London, 1883), p. 407.

[5] J. W. Dawson, "On the Eozoic and Palaeozoic Rocks of the Atlantic Coast of Canada, in Comparison of those of Western Europe and the Interior of America," *Quart. Jour. Geol. Soc. London*, Vol. XLIV (1888), p. 809.

no other explanation occurred to him to account for some aspects of the boulder transport. Sayles and Keith have described what look like varves associated with conglomerates at Lévis and Lake Champlain.[1] Coleman has strongly championed glaciation by an ice-sheet of continental type, and claims that, except for the obliteration of striae by mountain-building stresses, the conglomerates have in every respect a glacial character.[2]

We offer the following minor criticisms: (1) Varves are difficult to diagnose. (2) It is not clear why striae should be destroyed while neighboring graptolites have been spared. (3) The conglomerates we have examined have much less matrix than is common in boulder clays and are devoid of the bedding so characteristic of glacial gravels. (4) The great distance which Coleman thinks some of the boulders have traveled to reach the conglomerates is probably illusory. Raymond has given convincing reasons for supposing that the Lévis conglomerates have been thrust over their source, now hidden from view. It must not be imagined that the limestone conglomerates along Logan's line are always interbedded in shales. Walcott has described several resting on limestone (1894).

A much more important criticism has been suggested by Ruedemann. Speaking of the Trenton conglomerate of Rysedorph Hill, Rensselaer County, New York, he says: "The action of coast ice . . . . may in the writer's judgment be excluded here on account of the presence of the Trenton fossils, including corals, in the matrix."[3] Let us view the subject as a whole. The conglomerates of Logan's line were formed intermittently through Cambrian and Lower and Middle Ordovician times. Their material was derived from neighboring Cambrian and Ordovician limestones, that together constitute one of the greatest limestone developments of the earth's history. A large proportion of the boulders in the conglomerates consists of pene-contemporaneous limestone, and the matrix of the conglomerate is often charged with loose, thick-walled

[1] R. W. Sayles, "The Dilemma of Paleoclimatologists," *Amer. Jour. Sci.* (5th ser.), Vol. III (CCIII) (1922), p. 457; A. Keith, "Cambrian Succession of Northwestern Vermont," *ibid.*, Vol. V (CCV) (1923), p. 135.

[2] A. P. Coleman, *Ice Ages Recent and Ancient* (London, 1926), p. 202.

[3] *Op. cit.*, p. 110.

shells of species found in the boulders. Geographical exploration, in keeping with chemical physiology, assures us that important limestones are the products of warm seas. It seems incredible that the Cambro-Ordovician limestone platform, during the period of its growth, should intermittently have nourished continental glaciers, or even that its marginal reefs should have been exposed to the ravages of ice-floes.

Wildflysch and blocs exotiques.—The landslip conglomerates of the Quebec district forcibly recall the Wildflysch of the Alps with its *blocs exotiques*. Flysch is a name applied in Switzerland to sandstone-shale developments of the early Tertiaries in contrast with the contemporaneous nummulitic limestone facies. Flysch is termed "wild" where the bedding is disorderly, for the most part a result of tectonic disturbance. It is a very common feature for Wildflysch to carry breccias and irregular trains of boulders (*blocs exotiques*). Single boulders are sometimes as large as cottages, and may consist of either crystalline or sedimentary material, which it is often impossible to match among neighboring exposures on the north face of the Alps. In 1834 Studer erected a hypothetical chain in this position with the suggestion that nowadays it is mostly hidden from view through erosion and overthrusting. In 1884 Schardt sought aid in ice-transport—a view that still has adherents—but in 1890 he discarded this notion in favor of Studer's northern marginal chain. In 1893, he put aside both these theories and, arriving at the modern nappe-interpretation of the Alps, he recognized the breccias of the Flysch as submarine landslips detached from the fronts of northwardly advancing thrust masses.[1] The literature is large and always increasing. Schardt's 1898 paper, just quoted, serves as an excellent introduction, while important contributions by Lugeon[2] and Tercier[3] put the reader in touch with modern developments. Overfolds and thrusts have complicated the story even

[1] H. Schardt, "Les regions exotiques du versant nord des Alpes suisses," *Bull. Soc. vaudoise Sci. naturelles*, Vol. XXXIV (1898), p. 215.

[2] S. M. Lugeon, "Sur quelques conséquences de la présence de lames crystallines dans le soubassement de la zone du Niesen (Préalpes suisses)," *Comptes rendus Acad. Sci. Paris*, Vol. CLIX (1916), p. 778; "Sur l'origine des blocs exotiques du Flysch préalpin," *Eclogae Geol. Helvetiae*, Vol. XIV (1916), p. 217.

[3] L. W. Collet, *The Structure of the Alps* (London, 1927), p. 251.

more in the Alps than along the Logan line. It is a relief to turn to Scotland for a simple illustration of submarine landslipping.

Scottish analogy.—At Brora, on the east Highland coast, a long outcrop of Trias and Jurassic lies faulted down against much more ancient rocks, mainly flat-bedded Old Red sandstone. There is no suggestion of the proximity of a cliff during the deposition of the first thousand feet of this Mesozoic succession. Continental Trias is followed conformably by marine Jurassic which includes an important estuarine development in the same position (approximately Bathonian) as the Great Estuarine series of the west Highlands or the Upper Estuarine series of Yorkshire. This estuarine series is covered by marine sediments (mostly shales and sandstones) referable to the Callovian, Oxfordian, Corallian, and a hundred feet of the Kimmeridgian. Then follow 500 feet of Kimmeridgian shales with recurrent intercalations of boulder beds that are made up of Old Red sandstone blocks, large and small—one monster lying prone, with its bedding vertical, measures $150 \times 90 \times 30$ feet. Various explanations have been given of these boulder beds. Some invoke glacial assistance, but of recent years Woodward, Crampton, Macgregor,[1] and Lee[2] have realized that the boulders represent material fallen from a cliff that stood where now the boundary fault is seen.[3] Although not hitherto recognized as such, this cliff must obviously have originated as a fault scarp developed with attendant earthquakes in Kimmeridgian times. The question arises as to whether it functioned as a coastal cliff or was wholly submarine. The latter seems to have been the case. "Isolated blocks," we read, "are occasionally embedded or rather sunk into the Kimmeridge shales, the laminae of which are contorted and follow their contours," but groups of blocks have a matrix which passes "from hard homogeneous calcareous sandstone into shelly limestone" and contains four conspicuous coral and brachiopod species that are un-

[1] M. Macgregor, "A Jurassic Shore-Line," *Trans. Geol. Soc. Glasgow*, Vol. XVI (1916), p. 75, Plate III.

[2] G. W. Lee in "The Geology of the Country around Golspie, Sutherlandshire" (Sheet 103), *Mem. Geol. Surv., Scotland* (1925), p. 107 and frontispiece.

[3] W. H. Norton, "A Classification of Breccias," *Jour. Geol.*, Vol. XXV (1917), pp. 171, 172, has given an explanation which combines earthquakes with landslides and in many respects anticipates our own.

known in the intervening shales.[1] No complete explanation has previously been offered of these shells, but their analogy with the matrix fossils of the Quebec conglomerates seems to furnish a clue. The upthrow side of the fault presumably reached into clear, shallow, wave-tossed waters. There the hard platform of Old Red sandstone lost its unconsolidated cover of Mesozoic mud and sand. Thick-shelled organisms grew upon it, and these, along with débris of the Old Red sandstone, were spread by intermittent landslips over muds that gathered in still waters at the foot of the developing fault scarp. Continuance of faulting and erosion has now totally destroyed all trace of the clear-water Kimmeridgian where it formed on the upthrow side of the fault. In fact, for considerable distances the Old Red sandstone is denuded and an older underlying granite lies exposed to view.

Considerable support to this interpretation is afforded in Skye on the west coast of the Highlands. The latest Jurassic there preserved is of early Corallian age. At Camasunary, Wedd has shown that this formation is thrown by a 2,000-foot fault, which in turn is flatly transgressed by Upper Cretaceous.[2] There is thus independent evidence of important fault movements in the Scottish Highlands toward the end of Jurassic or the beginning of Cretaceous times.

No barrier between American and Atlantic facies.—Our interpretation of the conglomerates of the Quebec district leaves no room for a land barrier to separate the contemporaneous American and Atlantic facies of the district. We hold that the limestone and loose shells of the one facies were intermittently discharged as landslips down a submarine slope on to the muds of the other facies. We do not think that any satisfactory alternative can be offered which will account for the pebbles and the matrix fossils of the conglomerates, and at the same time retain an interfacies land barrier.

It would be a different matter if only one or two local conglomerate beds had to be explained. Ruedemann, inspired by Dana and Frech, adopted the conception of a migratory land barrier, and

[1] *Ibid.*, p. 108.

[2] C. B. Wedd in "The Geology of Glenelg, Lochalsh and Southeast Skye" (Sheet 71), *Mem. Geol. Surv., Scotland* (1910), pp. 9, 150, Fig. 2.

fitted the Trenton conglomerate of Rensselaer County, New York, into a scheme of oscillatory movements.[1] The adjustments that he contemplated are, however, so special that one cannot expect them to have been repeated time after time in connection with a narrow isthmus, hundreds of miles long.

Ulrich and Schuchert, writing at the same time as Ruedemann, recall that Logan asked for a land barrier between facies as long ago as 1866.[2] They then proceed to develop a rather intricate sequence of isthmuses, but they leave the matrix fossils of the Quebec conglomerates unnoticed. On turning to Schuchert's *Text Book of Geology* for later information, we find that the intraformational character of the conglomerates is denied, without, however, any mention of the matrix fossils. Otherwise our views are fairly closely anticipated, since the conglomerates are interpreted as probable "rock slides of cliff origin" with included masses up to 150 feet in length.[3] Moreover, Schuchert in the short compass of this *Text Book* makes no mention of the "Quebec Barrier" which Ulrich and he had formerly employed to separate a "Lévis Channel" from a "Chazy Basin." In fact, he admits that the "St. Lawrence Seaways" with their shales and sandstones were "more or less in connection with the Central Interior sea."[4]

If asked to explain the difference of faunas in the American and Atlantic facies, we should suggest that the faunas have sorted themselves according to their physical environment. The fossils are no more distinct than the rocks in which they occur.

> The Cambrian to Ordovician deposits of Laurentia may be interpreted as having accumulated in a warm shallow sea that bathed the shores of a low desert continent. . . . . The Caledonian facies . . . . , commonly spoken of as Atlantic, British, or European, ... consists of muds and sands, washed down by rivers from the rain-swept heights of the growing Caledonian chain.[5]

The mechanical sediments characteristic of the Atlantic facies came from the east, and therefore could not scale the eastward-facing

[1] *Op. cit.*, pp. 108, 109.

[2] E. O. Ulrich and C. Schuchert, "Palaeozoic Seas and Barriers in Eastern North America," *New York State Mus. Ann. Rep. 55* (1903, for 1901), p. 634.

[3] C. Schuchert, *A Text Book of Geology* (2d ed., 1926; New York), Part II, p. 204.

[4] *Ibid.*, p. 230.

[5] E. B. Bailey, "Across Canada with Princeton," *Nature*, Vol. CXX (1927), p. 674.

incline of Logan's slope, even where it was completely submerged. Of course this slope did not remain stationary during Palaeozoic times. It may safely be credited with many of the migrations hitherto attributed to land barriers; in fact, readers will readily appreciate that the slope and land-barrier theories have much in common, so long as the slope is oriented to oppose distribution of terrigenous sediment.

CONCLUSION

In our paper we recall the stirring year of 1860, when the mountain stratigraphy of Eastern Canada was first read with sufficient clarity to enable Logan to establish his famous line of slope and thrusting. Later work, notably by Lapworth, Walcott, Ruedemann, Raymond, and Clark, has given us a comprehensive view of the recurrent conglomerates that follow the course of this line. We have interpreted these conglomerates as submarine landslips detached during successive subsidences along the hinge of the Logan slope. We have also claimed that their nature is inconsistent with any theory of a land barrier separating American and Atlantic facies. Logan's slope often succeeded in dividing facies by restricting the westward travel of mud.

Postscript.—A review[1] directs attention to research that has followed the great Japanese earthquake of 1923. According to Yamasaki, soundings show submarine fault scarps, in connection with which there occurred, in 1923, a maximum subsidence of 200 meters and a maximum upheaval of 250 meters, "while the northern flank of the submarine range . . . . experienced a great slip 10 km. long, similar to a mountain slip on the land surface, filling the floor of the furrow with débris 230 meters in thickness."[2]

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[1] C. D., "The Origin of the Japanese Earthquake of 1923," *Nature*, Vol. CXXI (1928), p. 340.

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MEANDERING IN TIDAL STREAMS[1]

DONALD C. BARTON[2]

ABSTRACT

The thesis and its corollary have been proposed by Campbell that streams flowing essentially at and below tidal level have no power to meander, and that meanders in such streams are indicative of drowning. The Brazos River, Texas, is tidal for the lower 48½ miles of its course; it is discontinuously meandering throughout that distance, and a meander within a mile air-line distance from the coast has shifted 1,600 feet coastward since the first survey of the river in the seventies of the past century. The problem of the meandering involves a consideration of many factors. Special conditions of some of the factors aid the meandering of tidal streams, and a change of these conditions may leave stagnant tidal meanders not due to drowning. The paper does not pretend to be a finished study of the problem, but its purpose is to show the necessity of a more thorough study of meandering, especially the meandering of tidal streams.

The thesis that streams flowing at tide level have no tendency to meander nor power to enlarge or to cut off meanders already in existence is presented by Campbell[3] in an interesting and suggestive paper. His argument is based on the study of the Mississippi, the San Jacinto (Texas), and the James rivers. The problem, as he formulates it, is not concerned with any tidal phenomenon of the streams in the sense that there need be any tide in the streams, but with the behavior of streams that are flowing with their water level very closely at, and the bottom of their stream channel very considerably below, the water level of a lake, tidal or tideless bay, gulf, or ocean into which they are flowing; and in his conclusion he states that the problem is applicable to all submerged stream valleys, no matter whether their submergence is due to an invasion of the sea or of fresh water from some inland lake. The application that he makes of his thesis is its corollary that the presence of meanders in a tidal stream is an indication of subsidence. The explanation that

[1] The surveys of the Brazos River and other information regarding the Brazos River were obtained through the courtesy of B. Cannon and L. Mims, of the Freeport Sulphur Company.

[2] Consulting geologist and geophysicist, Houston, Texas.

[3] M. R. Campbell, "Meaning of Meanders in Tidal Streams," *Bull. G.S.A.*, Vol. XXXVIII (1927), No. 3, pp. 537–55.

he suggests for the inability of tidal streams to meander is that when the river reaches tide level the current is flowing in a more or less well-defined channel of water, and that the confining banks on either side are banks of water rather than banks of earthy material.

This law of stream behavior is not obeyed by the Brazos River, a tidal stream in the sense of Campbell's use of the term, as well as in the strict sense of having a tide. Although the amount of the meandering and the number of meanders in the tidal reaches of the Brazos are considerably less than farther upstream, the river is actively eroding the outer bank and depositing on the inner bank of most of the bends in the tidal reaches; survey records show extensive movement of a meander within 3 miles by stream from the gulf; and within the past few years the neck of a meander a few miles farther upstream was cut through.

The Brazos River is one of the major rivers of Texas. It rises in the eastern part of the West Texas Permian basin, flows completely across the Gulf Coastal Plain, and empties directly into the Gulf of Mexico near Freeport, Texas, in contrast with the San Jacinto River, which rises wholly within the Gulf Coastal Plain and empties into the head of Galveston Bay about 25 miles inland from the gulf. The Brazos River, the next main stream to the west, is about 45 miles from the San Jacinto. It is about twice the size of the latter.

The course of the river in its tidal reaches, that is, from the mouth to Bolivar Falls, a distance of 48.5 miles at the time of the survey, is shown in Figure 1. The data are from a survey by Corps of Engineers, U.S.A., in 1900, and the map gives the course of the river as of that date. The water level at the time of the survey sloped from +3 feet above mean low gulf tide-level at Bolivar Falls to zero at the mouth. The average elevation of the bottom of the main stream channel sloped from −10 feet mean low Gulf tide at the foot of Bolivar Falls to −15 feet M.L.G.T. immediately above the mouth of Varner Creek 35 miles above the mouth, and from −20 feet M.L.G.T. immediately below the mouth of Varner Creek to −25–−30 feet M.L.G.T. at its mouth. At Velasco and Freeport, the diurnal tide ranges from $1\frac{1}{2}$ to 2 feet. During periods of low water, according to the report, the diurnal tides extend upstream

to Bolivar Falls. In the lower 48½ miles of its course the Brazos River is flowing essentially at and below mean gulf-level and conforms to Campbell's type of "tidal" streams as well as having a tide.

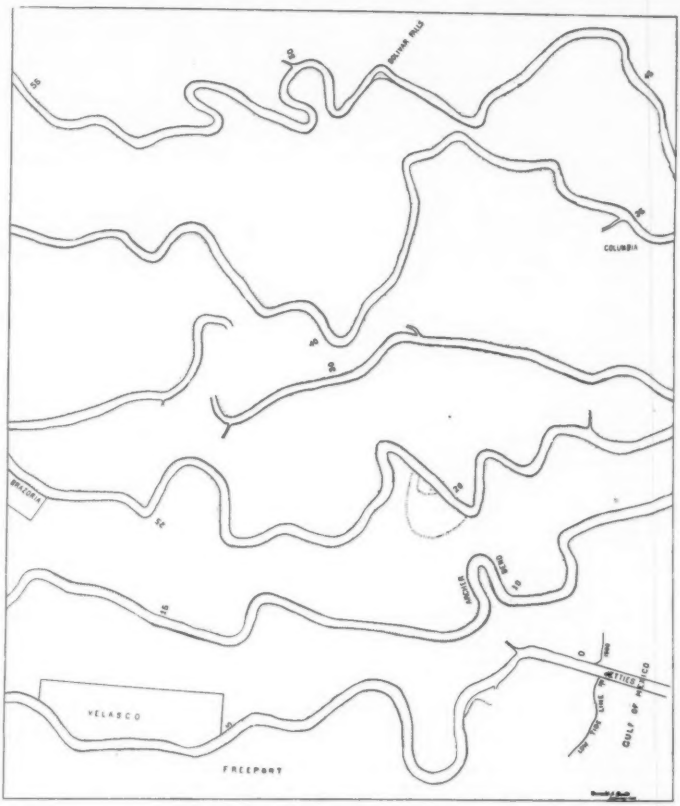

FIG. 1.—Course of Brazos River from vicinity of Bolivar Falls to the mouth. Survey, Brazos River, Texas, from its mouth to the city of Waco, Corps of Engineers, U.S.A., House Document No. 450, 56th Congress, 2d Session.

A tendency to meander is shown throughout that lower 48½ miles of the course of the stream, although in general the course is not meandering. Two rather simple meanders, one "S" meander and one cut-off meander, were present in 1900. For some 27 out

of the $48\frac{1}{2}$ miles, the river is bending and curving slightly rather than meandering. For 21 out of those 27 miles the outer bank of the meander was pictured by the surveyors as being very steep and the inner bank as being gently sloping, indicating that the stream apparently had been eroding the outer bank and filling on the inner bank. For 6 out of the 27 miles both the inner and the outer banks were shown as gently sloping, and on those bends, apparently, the stream had not been impinging strongly on the outer bank.

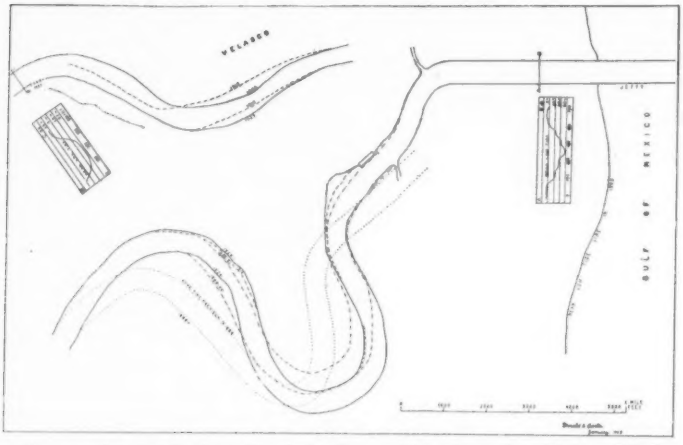

FIG. 2.—Longitudinal profile of the Brazos River from the vicinity of Bolivar Falls to the mouth, from the 1900 survey. The lesser irregularities of the profile of the main stream channel have been smoothed out.

The actual record of very considerable movement of meanders during the past forty years and the continuing movement at the present time is available in the actual instrumental surveys of the course of the river in the vicinity of Freeport and Velasco, and is shown by Figure 2. The shift of the position of the bend at the north end of the village of Velasco is shown by the successive positions of the banks in the successive surveys in Figure 3*a*. It was this bend that first drew the writer's attention to the fact that the Brazos River was actively meandering in its tidal reaches; an old road running off the caving outer bank of that bend out into space and the prograding opposite (inner) bank reminding the writer strongly of

the activities of that actively meandering stream, the Connecticut River, in Massachusetts. The actual slight enlargement of the meander just below Freeport and its shift about one-third of a mile gulfward within the past fifty years are shown by Figure 3*b*. This meander is within 3 miles of the gulf by stream and within 1 mile by air line. Its water-level is essentially that of the gulf; the bottom of its stream channel is 25–30 feet below mean gulf-level, and the general elevation of the marshy prairies on either side is only 1–2 feet above mean gulf-level. Yet this meander is in no way stagnant.

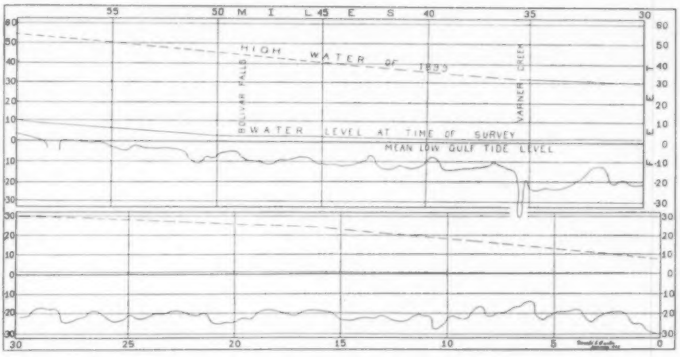

FIG. 3.—Surveys showing movement of meanders of the Brazos River. *A*, near Velasco, and *B*, below Freeport. Survey compiled by the Coleman Engineering Co., with additions by the Freeport Sulphur Co.

A cut-off of the Acher bend meander took place during the high water of 1922. Acher bend is the large meander a few miles above Velasco. The water-level at the time of the 1900 survey was at +2 feet M.L.G.T.L., and the bottom of the main channel averaged about −22 feet M.L.G.T.L. On account of the high water, the current apparently was able to short-circuit its course across the neck of the bend, but except in the case of intrenched meanders, that should be fully as common a method of cut-off of meanders as the erosion of the opposing banks to meeting.

The condition of the Brazos River at time of flood is quite different from its condition at times of normality. The levels of the water in the 1900 survey apparently are those of a period of normal condi-

tions. During times of flood, the water level at Bolivar Falls may rise from its normal position about +3 feet above mean low gulf tide-level to 35–45 feet M.L.G.T.L.; and the slope of the water surface for the stretch from Bolivar Falls to the gulf may rise from its normal value of about 0.04 feet per mile to 0.6–0.8 feet per mile. During normal periods the river flows rather quietly, is relatively clear for a stream not in hard-rock country, and is apparently doing practically no work of erosion and deposition. It seems probable that most of its work of erosion, transportation, and deposition is accomplished exclusively during times of flood, and that the stream has the tendency to meander only during times of flood, and that most of the meandering is accomplished at those times. But during those times of flood the whole lower 48½ miles of the Brazos will not be so tidal either in the strict sense or in Campbell's sense of the term as it will during normal times. The water-level in the lower half dozen miles, however, will be only very slightly higher than the level of the gulf, and the stream there will still be tidal in both senses of the term.

The present tendency to meandering should lead ultimately to the development of a considerable number of meanders in the lower 48½ miles of the river if the present conditions continue unchanged or even if there were a slight submergence. A submergence of 10 feet, which is greater than the probable submergence in the lower courses of the San Jacinto River,[1] presumably would not cause any very great change in the behavior of the Brazos River in the lower 48½ miles of its course. The Brazos carries a heavy load of silt when in flood, and in times of high flood overflows its banks and actively builds up its natural levees.

If a slow subsidence were occurring, progressively lesser floods would send the stream out of its banks; and the building up of the

[1] Galveston Bay seemingly occupies the inter-delta depression between the ancient delta of the Brazos River on the west and of the Trinity River on the East. The outlines and extent of the depression have been modified secondarily by lateral wave erosion of the weak and unconsolidated sediments which rise only a few feet above the water level. It, and probably most of the other bays along the Texas coast, should not be taken as evidence of subsidence. Minor submergence of the lower few miles of the San Jacinto River is another question. As, however, the slope of the river and its flood plain are only some tenths of a foot per mile in the lowest reaches of streams like the San Jacinto, very slight subsidence would produce noticeable drowning.

levees would be increased concomitantly and would probably keep pace with the subsidence. The mean gradient both of the water level and the bottom of the channel would be slightly decreased for the whole stretch below Bolivar Falls. If the bottom of the channel were not built up to keep pace with the levees, the effective volume of the channel would be oversize in ratio to the volume of stream flow and would tend to reduce the stream velocity, which in turn would favor deposition and filling of the channel until the ratio of channel capacity to the volume of the stream flow were brought back to its present value. The natural levees and the bottom of the channel of the meander near Freeport would be built up simultaneously, and the same conditions of stream flow would then prevail as at present, and the meander should continue to move seaward, unless, or until, obliterated by the retrogression of the shore line consequent upon the subsidence. The whole lower course of the stream from above Richmond to the gulf ultimately should become adjusted to a cross-section like that at present and to a longitudinal profile with a very slightly lower mean gradient than the present one. Yet it seems doubtful that the gradient would be less at any point than the present gradient in the stretch where the Freeport meander is actively moving. The conclusion therefore follows that the present tendency to meandering would continue in the lower reaches of the Brazos even in face of a progressive slow subsidence.

If the subsidence were sudden, shore-line erosion and alongshore currents might obliterate the lowest few miles of the stream, but in general the present channel, aided by the natural levees, would tend to hold the current to its present course just as now happens in time of high flood; the levees would tend to be built up to the new gulf level, and at times of flood, above it; and the river would tend ultimately to adjust itself to the same profile as if the subsidence had been slow and progressive. The conclusion again is that the present tendency to meander would continue.

Although the slight reduction of the mean gradient of the stream (resulting either from the slow progression, or the sudden, subsidence) would probably reduce the rate of meander development, yet if given sufficient time, approximately the same set of

meanders should develop as under the continuation of present conditions.

If floods should cease to recur in the Brazos River below Bolivar Falls it would become a quiet tidal stream, and the meanders in those reaches would become stagnant. But the presence of those stagnant tidal meanders would not signify subsidence, but simply diminution of the volume of the stream flow. This might be due to a change in the rainfall, beheading of the river, capture of some of its main tributaries by some other stream, or some other such change.

TABLE I

ELEVATION AND GRADIENTS OF THE WATER LEVEL AND BOTTOM OF THE MAIN CHANNEL OF THE BRAZOS RIVER

	Reaches		
	Tidal	Middle	Upper
	Elevations in Feet above Mean Low Gulf Tide Level		
Normal level of the water	0– 3	3–46	46–96
Bottom of the main channel	−30–−10	−3–40	40–90
	Gradients in Feet per Mile		
Normal level of the water	0.06	0.86	1.0
Bottom of the main channel	0.4	0.82	1.0

A study of the course of the Brazos River across 100 miles of the coastal prairies and marshes suggests that, beyond a certain point, decrease of the stream's gradient and consequent decrease of stream velocity will cause a decrease in the ability of the stream to meander. The course of the Brazos across the coastal prairie–marsh zone is divisible naturally into three reaches: the lower or tidal reach from the mouth to Bolivar Falls 48½ miles from the mouth, the middle reach from Bolivar Falls about to the town of Richmond 100 miles from the mouth, and the upper reach from Richmond for some 60 miles upstream. The data regarding the elevation of the water level, of the bottom of the channel, and of the gradient of the stream are given in Table I. The change in stream gradient corresponds to a change in the gradient of the prairie. From Richmond to the gulf the slope of the ground is less than 2 feet per mile, and

from Richmond to the Hockley scarp just south of Sealy the slope of the ground averages about $3\frac{1}{2}$ feet per mile. Geologically Richmond is about at the rather indefinite contact of the Beaumont Clay to the south and the Lissie formation to the north. This is approximately also the position of Baton Rouge, which Campbell notes as a dividing-point in the meandering behavior of the Mississippi River. The Brazos in the upper of these three reaches is practically one continuous stretch of broad sweeping meanders with mean radii of curvature ranging from 1 to 3 miles (Fig. 4). In the middle and the lower reaches the course consists mostly of nearly straight stretches, in many places at a considerable angle with each other, and of an

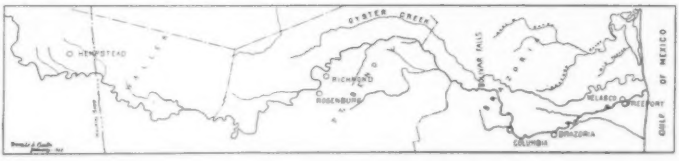

FIG. 4.—Map showing the course of the Brazos River from the vicinity of Hempstead to the mouth. The course and position of Big Slough, Austin Bayou, and the upper half of Bastrop Bayou are approximate only. Tributaries entering the Brazos River from the west above Rosenburg not shown.

occasional meander. With one exception, all the meanders are smaller than the meanders of the upper reach, and mean radii of curvature are about one-half mile. The number of fairly definite meanders is: in the middle reach at least 11, and in the lower reach, 7. The behavior of the stream in those three reaches suggests that the decreasing gradient of the stream from reach to reach is accompanied by a correspondingly decreasing power to meander, and that where a stream is flowing with approximately no slope it has approximately no power to meander—in contrast to Campbell's thesis that it completely loses the power to meander.

The possibility, however, that factors, differing from reach to reach, have affected the meandering in the three reaches must be taken into consideration. The character of the material in which the river has carved its channel is different in general above and below Richmond. In the upper reach the beds are more sandy, and in the middle and lower reaches are more silty and clayey, with the propor-

tion of clay to silt increasing gulfward. The difference in the character of the beds between the lower and the middle reaches is less than between the lower and middle and the upper. The life-history of the middle and lower reach may not have been the same, and that of the upper may have been yet different, and the actual ages of the three reaches may not be the same. The United States Bureau of Soils soil survey sheets suggest strongly an earlier course of the Brazos parallel to and slightly west of the present course of the tidal reach. The natural levees of the Brazos are composed of Yazoo sandy loam and show up on the soil map as narrow strips of that soil across the regionally predominant Sharkey clay. An entirely similar strip of Yazoo sandy loam is mapped as diverging from the right bank of the Brazos at a point near Manor Lake, about 43 miles from the mouth, and as extending to the gulf with a somewhat similar course a few miles west of the present course. The old channel is so much obliterated that the writer has never noticed it in crossing this belt of Yazoo sandy loam. This may have been an earlier main course of the Brazos, or that it may have been merely a former distributary of the present course. Oyster Creek, parallel to the Brazos and just a few miles to the east, is in its lower course a stagnant tidal stream, without tributaries, with a channel oversize for its present volume of flow, and with a well-developed set of natural levees. The maps show it rising a few miles north of Sugarland at a point not far above Richmond. As the channel at Sugarland is nearly as large as it is close to the gulf, and as only the through streams of this area seem to carry enough silt to form natural levees, it seems probable that originally Oyster Creek drew its water from the Brazos. It does not seem large enough ever to have carried the whole discharge of the Brazos. Its banks locally are composed of Yazoo silt loam, but mostly are composed of finer soils. Big Slough is an abandoned stream channel of slightly less size than Oyster Creek and is marked on the soil map by a very distinct pair of natural levees composed of Yazoo sandy loam. From a point 2 miles east of Oyster Bayou and about 15 miles back from the gulf Big Slough meanders in a generally south-southeastward direction into a coastal lagoon. To obtain the silt for the natural levees, Big

Slough must have been connected with some through stream, either Oyster Creek or the Brazos. Farther inland, along the west and southwest line of Harris County, there is a much older system of distributaries. They well may have come off from the Brazos above the 150-mile point on the present stream. It is therefore probable that before the river became intrenched in its present position it may have flowed in whole or in part in other channels. The date of origin of the present lower reach may be later than that of the middle reach, and the birth of the middle reach later than that of the upper reach.

A cycle of development theoretically should prevail for meandering. If a stream starts with a relatively straight course under conditions which may permit meandering, time to develop its full complement of meanders must be allowed. This time will be a function of the ability of a stream to meander. The absence of meanders in an extremely young stream may be due, not to inability to meander, but to insufficient time to produce meanders. If the lower reach of the Brazos is less meandering than the middle, and the latter is less meandering than the upper reach, the effective factor may be the length of time that each reach has had to develop meanders rather than its ability to meander. The point is one that should be considered in discussions of the ability of the Mississippi River to meander in its delta reaches. Below New Orleans the river is very young, and even as far upstream as Baton Rouge it still may be fairly young. It is of course improbable that in those reaches the Mississippi has much power to meander, but it also is probable that it has not had much time to develop meanders. Campbell's conclusion that the Lower Mississippi is not meandering will not be warranted until a more detailed study is made of those reaches of the Mississippi and until a more detailed analysis is made of the meandering of streams.

Various factors presumably affect the ability of a stream to meander, and a dependent interplay presumably prevails among some of the factors. Slope of the stream channel, volume of the stream flow, velocity of the stream flow, character and area of the cross-section of the channel, character and amount of the load carried by the stream, height and character of the banks, periodicity

and frequence and magnitude of floods, tides, and non-tidal fluctuations of the water level of body of water into which the stream flows, are factors that easily may affect the ability of a stream to meander.

The ratio of the volume of the stream flow to the area of the cross-section of the channel seemingly is an important factor to be considered in the discussion of the meandering of "tidal" streams. If the area of the cross-section of the water-filled channel becomes oversize in relation to the volume of the stream flow, the current may flow in banks of stagnant water in the manner suggested by Campbell, but also it seems certain that there would be a reduced velocity of flow over the whole cross-section that might readily be below the critical velocity necessary to cause erosion of the particular type of bank at that place. Decrease in the ratio of the volume of the stream flow to the area of the cross-section of the channel might be caused either by decrease in the volume of the stream flow or by the raising of the water level by drowning. Stagnant meanders at tide level in rivers which in Pleistocene time probably had a considerably greater volume than at present can be taken as indicating submergence only after the effects of the decrease in volume are evaluated as negligible.

Drowning of a given moderate amount should affect streams carrying much sediment differently from those carrying essentially none. A stream carrying no sediment is in equilibrium with any size of channel, although there will be a reduction in the velocity of flow proportional to the increase in the area of the cross-section of the water-filled channel. A stream that is carrying much sediment and that is in approximate equilibrium with a channel of given size will not be in equilibrium if the area of the cross-section of the water-filled channel is increased, and will tend to build up its bed until the area and shape of the cross-section of the channel and the velocity of the stream flow are approximately the same as before.

Streams carrying a considerable load of sediment in general will be flowing between natural levees as they approach the sea or a lake, and thus will not be flowing in a valley. The Mississippi below New Orleans and the Brazos below Bolivar Falls have no valleys. A stream that is carrying no load of sediment in general should be flowing at the bottom of a valley, although of course such a stream

in the position of the Brazos would have only a very small, faint valley. For example, Bastrop Bayou, a small stream a few miles east of Oyster Creek, carries very little sediment, and instead of natural levees like those of the Brazos, Oyster Bayou, and Big Slough, has a shallow valley a few feet deep and a few hundred yards wide. A moderate submergence would not increase the flooded area of cross-section of the channel of the Brazos type of stream as much as it would the Bastrop Bayou type. If the subsidence is slow, a stream carrying a sufficient load of sediment should be able to maintain itself in a constant relation to the rising water level. If the drowning of the lower part of the San Jacinto River was caused by a regional submergence of the coast, the Brazos has maintained its position against the rising water level, and is still meandering close to the gulf. The conclusion a priori would seem to be that a stream might continue to meander in spite of a tendency to the submergence of meander.

Fluctuations of level of the body of water into which the stream is flowing should greatly affect the ability of the stream to meander in its lower reaches. In a very shallow body of water, such as Galveston Bay, which nowhere is over 8 feet deep (outside of the artificial channels), a steady strong wind will pile up the water in the leeward part of the basin, and because of the shallowness, friction on the bottom will tend to impede the return flow of the water. In Galveston Bay winds may cause a change of several feet in the level of the water. Lowering of the water level at the head of such a bay should appreciably increase the velocity of flow in the lower reaches of a stream entering it, and might appreciably increase temporarily the ability of the stream to meander in the lower few miles of its course.

The presence of a considerable tide, such as the 20–50 foot tides of the Bay of Fundy, should complicate the problem of stagnant meanders in the tidal reaches of streams. The currents produced in tidal streams by such tides may be swift, both on the rising and falling tide. Johnson gives velocities of 4.8 knots at Hell Gate and of 6–12 miles per hour in the Severn.[1] Some of the tidal estuaries of the Bay of Fundy accomplish considerable erosion, as is shown by

[1] D. W. Johnson, *Shore Processes and Shore-Line Development* (1919), pp. 107, 114.

the uncovering of the ancient forest mentioned by Johnson and seen by the writer. As the zones of cut and fill on a bend are not greatly shifted by a reversal in the direction of the flow, a priori it would seem reasonable that tidal estuaries might possibly meander. Even with the moderate tides of the Atlantic seaboard of the United States, the velocity of the current in tidal streams should be increased for a few hours per day above the velocity that would prevail if there were no tide, although of course there will be a corresponding decrease at other hours of the day. That increase in velocity should produce a temporary increase of the stream's ability to meander. The tidal range at the head of any bay or in a tidal estuary, however, is very sensitive to constriction or widening of the channel through which the tide enters. Thus the advance of bay mouth bars, for example, would ultimately cause a decrease in the height of high tide and of the tidal range. If a considerable tide in an estuary does increase the ability of the stream to meander in its tidal reaches, a decrease in the range of the tide should cause a decrease in the ability of the stream to meander.

The conclusions which follow from this study of the Brazos River and from this analysis of the meandering of "tidal" streams are: First, that Campbell's law of the non-meandering of "tidal" streams cannot be wholly false, for a priori in any given situation there must be some critical velocity below which the stream will have no power to meander; and as the stream approaches and enters a body of standing water, the velocity of the stream must drop to, and then below, that critical velocity. Second, that Campbell's formulation of that law is not wholly correct: that is, stagnant, apparently drowned meanders in a "tidal" stream may owe their stagnation and apparent drowning to factors other than drowning of the stream. Third, that various factors affect in a complex way both the ability of a stream to meander and the behavior of meandering streams in "tidal" reaches as well as in higher reaches. Fourth, that under certain conditions some factors increase the ability of the stream to meander, and, conversely, the reverse of those factors, as well as other factors, decrease the ability of the stream to meander, or may make it impossible for the stream to meander. Conditions adverse to meandering, for example, are: under certain conditions a con-

siderable decrease in the volume of stream flow, or, under certain other conditions, drowning of the stream. Fifth, that stagnant meanders in a "tidal" stream may not be taken as indicating submergence of that portion of the stream, until the effects of all those other possibly causative factors have been evaluated as negligible.

The analysis which this paper has given of the ability of "tidal" streams to meander has not been meant to be a full and finished study of the problem. Its purpose has been to show probable cause for a yet deeper and more thorough study of the meandering of streams as a whole, as well as of meandering "tidal" streams, and to advertise the problem as an interesting, although somewhat involved and ramifying, one that is well worth further investigation.

A FAULTED PENEPLANE IN FERGANA: A REVIEW AND DISCUSSION

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ABSTRACT

Planed surfaces on areas of folded and faulted Paleozoic limestones constitute an important part of the present topography of the southern edge of the Fergana basin in Russian Turkestan. D. I. Mushketov, on the basis of evidence here reviewed, gives the interpretation that the surfaces are parts of a peneplane which was formed before Upper Cretaceous times and has since been faulted and partially stripped of its covering of later sediments. Observations of other geologists which tend to confirm or reject the conclusions of Mushketov are summarized. A discussion of the agents which produced the peneplane leads to the conclusion that it was formed by normal stream erosion.

To the west of the city of Osh, Fergana *oblast*, Russian Turkestan, is a group of flat-topped hills studied by D. I. Mushketov.[1] The surrounding country, which, around Osh, lies at a mean altitude of about 2,500 feet, is a part of the rolling foothill belt between the Alai Range (Fig. 1) and the Fergana basin. The hills extend 15 miles west from Osh to the Aravan River. The maximum width of the group is about 10 miles, and the average altitude of the flat tops is 5,000 feet. The hills are composed of sharply folded and faulted Paleozoic sediments ranging in age from Lower Devonian to Lower Carboniferous (Mississippian), with a total thickness of about 7,000 feet. The succession consists principally of metamorphosed limestones. Only the Lower Middle Devonian is represented by slates. The folds trend east-northeast.

The major part of the area of the Fergana basin and the Alai foothills is occupied by younger sediments ranging in age from Jurassic to recent. The base of the Osh Hills is surrounded by recent loess, gravel, and talus which have been piled up, in some places, high enough to separate a few minor knobs from the main group. In the middle of the group there are long, bare, flat-topped ridges. Two of the principal ones, Chil Ustun and Chil Mairam, are covered

[1] "Chil Ustun and Chil Mairam," *Mém. du Comité Géol.* (Petrograd, 1915).

over one-fourth to one-half of their height by limestone and slate talus. Some of the ridges out toward the border have been more extensively dissected, and all that remains is a line of conical knobs almost completely covered by their own weathering products. Some of the flat tops of the ridges, however, have been well preserved, as shown on the accompanying longitudinal profiles (Fig. 2). Mushketov made an estimate of the ratio of the area of the flat uplands to the area of the base of the group, obtaining a figure of 0.12. If the

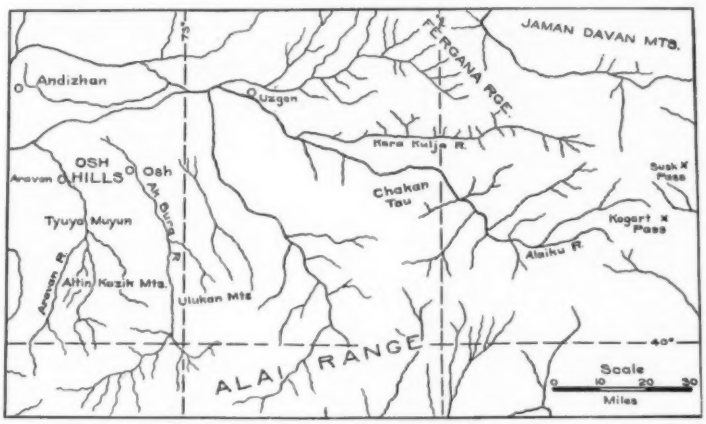

FIG. 1.—Index map of eastern Fergana and the western Tian Shan

débris covering the lower slopes were removed, this ratio would be increased to about 0.4.

The angles of the solid rock slopes vary from 30° on the slates to 70° on the limestones. There is a marked difference in slope on the north and south sides. The angles of the southern limestone slopes vary from 40° to 50°, while those of the corresponding northern slopes vary from 50° to 70°. Erosion is much more active on the southern slopes. Deep ravines and gullies are here more numerous. One of these gullies descending to the south causes the sharp break in the profile along the top of Chil Mairam.

The area of the flat uplands is now being reduced by enlargement of gullies. Erosion processes are, however, acting very slowly, and it is partially due to the nature of these processes that the large

upland areas have been preserved. No permanent streams flow out of the hills. Stream erosion is active only at the east and west ends of the group where the Paleozoic sediments are being removed by the Aravan and Ak Bura rivers. The hills are being reduced almost exclusively by mechanical weathering and by fragments rolling down the bare slopes on to the talus heaps.

The lack of any apparent relation between the structure of the folded Paleozoic limestones and the even tops of the ridges leads to the conclusion that they are parts of an erosion surface. The Osh Hills, however, are not the only locality in which an erosion surface cutting Paleozoic limestones may be seen. To the south of Osh along the Aravan and Ak Bura rivers recent erosion has removed the covering of younger sediments from strips a mile to a mile and a half wide on both sides of the rivers, exposing flat-topped ridges of Paleozoic limestone. The altitudes of the summits vary from 5,000 to 5,500 feet, with increase in respective altitudes southward. Mushketov mentions five such ridges, including Kuln Art and the ridge at the Tyuya Muyun radium mines. In addition, he observed other planed areas of Paleozoic limestones projecting barely above the general surface of the younger sediments in the area between the Ak Bura and Aravan. An erosion surface at about 9,000 feet elevation truncates the ridges at the base of the Alai Range and in some places extends as a bench up to the foot of the range. This feature was first noted by R. W. Pumpelly,[1] who saw it only from a considerable distance. Later it was given closer attention by Mushketov.

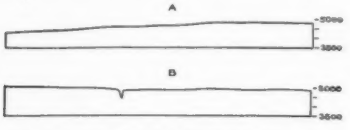

FIG. 2.—Longitudinal profiles of the central portions of Chil Ustun (*A*) and Chil Mairam (*B*). Vertical and horizontal scales equal (after Mushketov).

Similar planed surfaces on the Paleozoic rocks have been observed in the Alai foothills in the part of the belt extending 150 miles to the westward from Osh. V. N. Weber[2] followed one of them

[1] "Explorations in Turkestan," Expedition of 1903, *Pub. Carnegie Inst. No. 26* (1905).

[2] "Short Preliminary Account of an Excursion into Fergana in 1902," *Bull. Com. Géol.*, Vol. XXII (St. Petersburg, 1903).

on the ridge south of the fortieth parallel for some 30 miles eastward from the meridian of Khojent (160 miles west of Andizhan). Mushketov later visited the area studied by Weber and found that its physiographic features are similar to those of the foothill belt between Osh and the Alai Range. W. M. Davis[1] observed near Makhram, on the railway east of Khojent, "a high dissected dome of apparently crystalline core, wrapped around by colored sedimentaries: first a dark belt that lapped on the flanks of the dome; then a weak gray belt; then more resistant red beds. The colored belts are much narrowed as they curve around the northern base of the dome from east to west, as if they were torn by marginal faulting or tilted to steep dips." Although Davis gives no information on the nature of the core and apparently did not examine the material of the fans at the mouths of the ravines dissecting the dome, he describes certain features very characteristic of the ridges of Paleozoic sediments. This will become more apparent when the nature of their boundaries is considered.

In summation, it may be said that in the foothill belt of the Alai Range over a distance of several hundred miles there are numerous flat-topped areas of folded Paleozoic limestones. The absence of any relation between their surfaces and the structure of the Paleozoic sediments gives strong evidence that the even uplands are erosion surfaces. It might be concluded that the uplands at different altitudes were formed by different cycles of erosion. Certain major objections to this interpretation become apparent, however, after considering the geological history of the Fergana basin, the Alai Range, and the western Tian Shan.

The next sedimentary rocks younger than the Paleozoic are Jurassic continental beds consisting of siliceous breccias, conglomerates, and shales of different colors. At various horizons in the series there are a few coal seams. Rock salt and gypsum beds are absent. The Jurassic lies unconformably on the Paleozoic. It was deposited in basins and is therefore of rather local distribution. It varies in thickness up to 1,500 feet. Weber describes the sediments deposited in one of these basins which extended some 150 miles east-northeast

[1] "Explorations in Turkestan," Expedition of 1903, *Pub. Carnegie Inst. No. 26* (1905), p. 61.

from a point a short distance south of the fortieth parallel at the latitude of Khojent. The maximum north-south width of the basin was not more than 40 miles. The Jurassic has not been found in the vicinity of Osh.

In the Alai foothill belt the Jurassic is overlain conformably by a thin series of sediments with limestone conglomerates at the base passing upward into finer reddish continental sediments with gypsum beds. This part of the succession is probably of Lower Cretaceous age, since it passes conformably upward into a series consisting predominantly of loose clastic sediments containing minor limestone bands bearing a well defined Upper Cretaceous marine fauna. The Eocene is also represented by marine beds in conformity with the Upper Cretaceous. During Upper Tertiary times and up to the present the Fergana basin and the foothills of the Alai Range have been receiving continental sediments of irregular distribution containing numerous minor unconformities. In some places in the center of the Fergana basin the thickness of these sediments reaches 4,000 feet.

The region now occupied by the Fergana basin and its southern border zone was thus subjected to a long period of erosion from the end of the Mississippian period to the end of the Jurassic period, except in the restricted areas where the Jurassic sediments were accumulating. The region still remained above sea-level until the beginning of the Upper Cretaceous, for the Lower Cretaceous is represented by continental sediments. In general, their areal distribution closely follows that of the Jurassic.

The nature of the land surface over which the Upper Cretaceous sea advanced may well be considered here in connection with the general history of the region. The tops of the limestone ridges exposed in the strips of the Paleozoic floor along the Ak Bura and Aravan rivers pass laterally from the river beneath a cover of younger sediments, but it is found that the Cretaceous abuts against the flanks of the limestone ridges. Weber observed exposures in the Alai foothills to the west in which the basal Cretaceous, consisting of conglomerates derived from Paleozoic limestone, lies upon Paleozoic slates. When followed toward the limestone areas the conglomerate becomes more angular and passes into talus breccia, which abuts against a steep surface of solid limestone. This he interprets

as being the result of the entrance of the Cretaceous sea into the lowlands, leaving the hills standing out as islands. The same interpretation is accepted by Mushketov, who speaks of the "penetration of the Upper Cretaceous sea into an already prepared relief."

The Upper Cretaceous sediments, however, do not merely surround the limestone uplands in all cases. Weber observed undisturbed marine Cretaceous sediments lying on an even surface of the Paleozoic limestones in the line of hills to the south of the fortieth parallel near the longitude of Khojent. He was able to follow out the contact over a considerable area. The Cretaceous cover is here fairly continuous, but short streams have cut through it into the Paleozoic, exposing the even floor beneath the Cretaceous. Both the floor and the sediments dip very gradually to the north. Remnants of red breccias and conglomerates are found on the planed bench following the southern border of the small Alaiku basin (Fig. 1). They bear no marine fauna and are probably of continental origin. Because of their general similarity to the Cretaceous continental deposits, Mushketov believes that they are of Cretaceous age. Since they occur close to the base of the Alai Range, which rises from the south edge of the bench, it is quite possible that they represent a continental phase of the clastic deposits laid down in the Cretaceous sea.

Mushketov accounts for the surface features of the region at the time of the Upper Cretaceous marine transgression as follows: "After the folding of the Mississippian and older rocks, erosion reduced the surface of the region to a flat or almost flat surface, i.e., to a peneplane. This was followed by a period of erosion which cut into the less resistant rocks, leaving the more resistant ones standing as flat uplands."

He gives no hint as to the character of the change which stopped the reduction of the surface to a peneplane outside of the basins receiving the Jurassic sediments and caused more rapid erosion to begin on the less resistant rocks, in this case the slates. The respective characters of the Jurassic and Lower Cretaceous sediments suggest a possible cause for this change. It is to be recalled that the Jurassic sediments contain coal beds, and the clastic sediments are composed predominantly of siliceous fragments and not of lime-

stone fragments. Because of the absence of fossils, the usual criterion for the differentiation of the thin series of sediments, thought to be of Lower Cretaceous age, from the underlying Jurassic is the presence in the former of limestone fragments and beds of gypsum. This indicates a change from a humid climate favorable to the growth of vegetation and solution of limestone during the Jurassic to a more arid climate during the Lower Cretaceous. If this climatic change were accompanied by a slight uplift of the peneplaned areas outside of the Jurassic basins, the more arid Lower Cretaceous climate would favor differential erosion operating predominantly on the slates. In the absence of abundant rainfall the massive limestones would hardly be affected by solution, while the slates would be more susceptible to mechanical agencies and would be carried away. Certain amounts of limestone fragments would also be weathered from the sides of the limestone uplands and thus give origin to limestone conglomerates in the Lower Cretaceous sediments.

The geological history of the western Tian Shan region as given by F. Machatschek[1] is very similar to that of the Fergana basin and the Alai foothills. At the end of the Carboniferous there was a strong orogenic movement accompanied by the intrusion of large igneous bodies. This was followed by a period of erosion which produced, before Upper Cretaceous times, a peneplane cutting the Paleozoic sedimentaries and the various intrusive rocks. The sea penetrated to the western margin of the region now occupied by the range in Upper Cretaceous times, but did not extend farther eastward until Eocene times. Since Eocene times the ranges have been uplifted with only tilting and warping and no marked folding. The old peneplane now forms the surface of the extensive rolling "syrt" uplands at altitudes of 11,000–12,000 feet. On the syrt uplands there are a few inwarped or infaulted Tertiary remnants.

Since the time of peneplanation the Fergana basin has not been subjected to any proper folding movements. Weber's twelve north-south cross-sections[2] of the foothill belt extending 150 miles west of Aravan show the Jurassic and later sediments disturbed only by monoclinal folds and faults with downthrow to the north. These

[1] "Der westlichste Tienschan," *Peterm. Mitt. No. 176* (1912).

[2] *Op. cit.*, map opposite p. 14.

movements also gave a gentle northward inclination to the Cretaceous floor. In a later publication[1] on the same area he describes similar features but gives more details. There are slight differences in strike between the folds in the Paleozoic sediments and the flexures and faults affecting the later sediments. In the area around Osh and to the south of it, investigated by Mushketov, there are similar faults and monoclinal folds in the later sediments, but the strikes of the folds and faults in the Paleozoic rocks and in the later sediments are generally accordant.

In the vicinity of Osh the Jurassic is absent. The Cretaceous and Eocene are conformable and have been disturbed by faults,

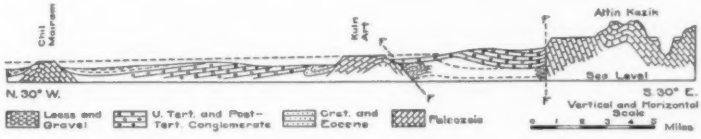

FIG. 3.—Diagrammatic cross-section from the Osh Hills to the base of the Alai Range (after Mushketov).

which form the boundaries between small basins occupied by later sediments, and the flat-topped ridges of Paleozoic rocks, as shown diagramatically in the cross-section (Fig. 3). The faulting has given local steep dips to the Cretaceous and Eocene and in some places the beds have been overturned. The Upper Tertiary and later conglomerates have been affected only slightly by these faults, and in some places lie on the Cretaceous and Eocene with pronounced unconformity. It is thus apparent that the major faulting took place before the deposition of the Upper Tertiary. It is extremely likely that fault movements are still going on, since earthquakes are of rather frequent occurrence in many parts of Turkestan.

The fact that remnants of Cretaceous sediments are not found on all the planed surfaces of folded Paleozoic limestones might still permit the surfaces to be interpreted as representing different erosion levels formed in different cycles of erosion if there were no clear relation between the displacement of the faults and the altitudes

[1] "Geological Explorations in Fergana in 1909 and 1910," *Bull. Com. Géol.*, Vol. XXIX (St. Petersburg, 1910), No. 8.

of the various planed Paleozoic areas. The upland surface of the Osh Hills is at an altitude of about 5,000 feet. The tops of the ridges exposed to the south along the Ak Bura and Aravan rivers and the surfaces of the Paleozoic rocks projecting through the younger sediments between the two rivers are at altitudes of 5,000–5,500 feet. There is a gradual southward increase in the altitudes of the respective tops. An imaginary surface connecting the various flat tops would have a downward inclination to the north about equal to that of the latest sediments. The southward extension of this surface would be some 3,000 feet below the surface of the bench at the northern base of the Alai Range. The bench is bounded on the north by a steep scarp, and here there is stratigraphic evidence that the scarp is the result of a fault with throw of about 3,000 feet. This fault has been followed westward into the area studied by Weber and it has produced the same displacement of the erosion surface cutting the Paleozoic rocks.

From the foregoing it seems logical to conclude that the erosion surfaces on the various areas of Paleozoic rocks are all parts of a faulted and tilted peneplane which was formed between the time of folding of the Paleozoic sediments and the beginning of the Cretaceous marine transgression.

In some places the peneplane is now beneath a cover of Upper Cretaceous sediments, while in others the cover is younger. In still others the planed limestone surfaces are bare. It seems extremely unlikely that the peneplane was once covered everywhere by marine Cretaceous sediments. A peneplane is not a level surface, and thus would not be covered in all places at the same time by an advancing sea. It is quite probable, moreover, that the marine transgression was caused in part, at least, by an absolute downward movement of the land surface and not merely by a general rise of sea-level. Such a depression of the land surface would probably lead to some warping and cause an even more unequal distribution of the Upper Cretaceous sediments. It is necessary, however, to account for the survival of the even surfaces from Upper Cretaceous times to the present.

The removal of the cover from a buried peneplane without dissection of the peneplane itself is favored by (1) a cover very much

less resistant to erosion than the rocks on which the peneplane is cut, and (2) by erosion of the cover when the peneplane lies only a short distance above the base-level of erosion.

The first condition is fulfilled in the case of the removal of the cover of later sediments from the surface of the Paleozoic limestones, for the limestones are compact metamorphic rocks, while the younger sediments are predominantly loosely cemented conglomerates and sandstones. Along the valleys of the Ak Bura and Aravan stripping of the conglomerate cover is now proceeding. In the areas between the limestone ridges the conglomerates have been removed from the valley bottom for a mile or more on each side of the river, which here flows in a broad valley. Erosion is also removing the cover from the tops of the ridges without destroying their form. It is only where the large main streams cross the ridges that the limestones have been extensively removed, but only sufficiently to permit the streams to pass through steep-walled canyons.

The main streams descending from the Alai Range and crossing the foothill belt are now actively cutting downward. The extent to which erosion in this direction can continue is not determined by a base-level surface, one edge of which coincides with mean sea-level. The principal sources of water of the main streams are well within the Alai Range. After crossing the semi-arid foothill belt the rivers spread out on great alluvial fans at the edge of the Fergana basin and disappear. Erosion is thus controlled by a temporary base level.

Since the retreat of the Cretaceous-Eocene sea, erosion has not been continuous. It is found that the Cretaceous and Eocene in the foothills are locally upturned, and in some places overturned, along faults and monoclinal flexures. Here there is pronounced unconformity between them and the Upper Tertiary conglomerates. In other places the Upper Tertiary apparently lies conformably upon the Eocene. Within the Upper Tertiary series there are numerous minor unconformities, none of which represent long gaps in sedimentation. The general sequence of events causing these relations is as follows: (1) Retreat of the sea. (2) Differential uplift and depression of blocks along faults and flexures accompanied by removal of all or part of the cover from the peneplaned Paleozoic limestone

surfaces buried in the higher blocks. (3) Deposition of Upper Tertiary and still younger sediments with only short and local interruptions. (4) Erosion resulting in the exposure of the limestone surface as seen at present.

The Alai foothills are in a peculiar location between the upfaulted Alai Range and the depressed Fergana basin. The differences in their respective topographic features, which will be described later, give strong indication that the foothills were the hinge-line to the south of which the predominant movement was elevation, and, to the north, depression. It seems quite likely, therefore, that during the post-Eocene period of local erosion of the more elevated blocks the foothill belt formed the boundary between a region of active erosion, the Alai Range, and a region of active deposition, the Fergana basin. In such circumstances erosion would have proceeded when the surfaces of the upthrown blocks were not far above the local base level, a condition which would favor stripping of the buried erosion surface on the Paleozoic limestones without its destruction. Successful stripping at this stage would also be favored by the fact that the Cretaceous and Eocene sediments were not then as well consolidated as at present.

One is led to ask why there are minor unconformities within the Upper Tertiary series of continental sediments and why the foothills are now in a cycle of erosion following an interval of predominant deposition. These questions cannot be adequately discussed without going too far from the general subject of the effect of the faulted pre-Cretaceous peneplane on the present topography of the region. The following suggestions are made to account for the two phenomena:

1. The minor unconformities within the Upper Tertiary series were caused by minor differential uplift of certain fault blocks which carried the surfaces of some of them above the general surface of deposition.

2 The foothill belt is now subject to erosion which is exposing portions of the peneplane formed before the Cretaceous marine transgression because (*a*) the axis of differential movement between the Alai Range and the Fergana basin has moved northward from the foot of the range, or (*b*) the climatic change which has produced

local glaciation within the Alai Range has caused an increase in precipitation in the foothills. A change of this kind would cause the mouths of the streams flowing from the range to move northward, converting the region between the range and the new mouths into a zone of erosion instead of a zone of deposition. The last hypothesis has a better foundation, since there are now glaciers within the range and there is abundant evidence that they were once more extensive. This explanation would hold only in the event that the glaciation was caused by increased precipitation and not by a colder climate.

The area where Weber saw the Cretaceous cover and the underlying even Paleozoic limestone floor, both dissected by short streams, gives conclusive evidence that in one place, at least, erosion is not merely stripping the surface of the limestones, but is also destroying it. Here the cover is comparatively old and well consolidated. Consequently there is no great contrast in resistance to erosion between the floor and the cover. It is hardly to be expected, moreover, that successful stripping of the peneplane would proceed everywhere. On the other hand, the evidence that the foothill belt has been predominantly a zone of deposition, with only short intervals of local erosion, from the time of the retreat of the Eocene sea up to comparatively recent times makes it extremely unlikely that there has been, since Lower Cretaceous times, an interval of erosion of sufficient length to produce the planed tops of the Paleozoic limestone ridges.

The general topographic features of the Alai Range and its northern foothills provide striking confirmation of the history of deformation and deposition outlined before. The surface forms of the Alai Range are the result of normal, youthful erosion, both fluvial and glacial. Such rivers as the Ak Bura and Aravan, rising within the range here, flow in canyons which are in some places 7,000 feet deep. Their courses are transverse to the strike of the folds in the Paleozoic rocks. They are therefore consequent streams flowing northward from the axis of most rapid upward movement during the differential uplift which began in post-Eocene times. They have very few important subsequent branches.

The rivers flow out of the mountains across the foothills in a

general direction from south to north. In crossing the minor basins containing post-Paleozoic sediments the rivers flow in broad valleys, but pass through the Paleozoic ridges in steep-walled canyons, in places several thousand feet deep and more than five miles long. There are examples of parallel streams separated in a basin by a divide of soft sediments only a few feet high. Instead of joining here they continue through long, deep, parallel limestone canyons situated only half a mile apart. In the next basin they join. In addition some of the ridges are cut transversely by dry gullies. One is led to the conclusion that the streams are either superimposed or antecedent. It is extremely probable that they are superimposed in certain parts of their courses and antecedent in others, since some of the ridges are still partially covered by younger sediments, while the faults which affect the Cretaceous and Eocene and, to some extent, the younger sediments, show that there have been vertical movements which would lead to the formation of antecedent streams.

All the geologists who have worked in the southern border of the Fergana basin and in the Tian Shan agree that the present topography of these regions is partially determined by raised and tilted erosion surfaces. There is, however, considerable difference among them as to the date of peneplanation. Mushketov, Machatschek, Friederichsen,[1] and Keidel[2] all conclude that peneplanation took place before the Turonian (Coloradoan), basing their conclusions on observations and deductions such as those given before. R. W. Pumpelly[3] and Ellsworth Huntington[4] state that the peneplane was formed during the Pliocene. Pumpelly gives no stratigraphic evidence to support his conclusions. Huntington and W. M. Davis both recognized the peneplane as being of post-Paleozoic date, since it cuts the folded Paleozoic sediments and the igneous

[1] M. Friederichsen, "Forschungsreise in den zentralen Tian-schan und dsungarischen Alatau" (1902), *Mitt. Geogr. Ges. Hamburg* (1904).

[2] "Einige Berichtigungen zu meinen Arbeiten über den Tian-schan," *Centralbl. Min.* (1907).

[3] "Explorations in Turkestan," Expedition of 1904, *Pub. Carnegie Inst. No. 73*, Vol. II (1908).

[4] "Explorations in Turkestan," Expedition of 1903, *Pub. Carnegie Inst. No. 26* (1905).

rocks intruded into them. Davis makes no attempt to place an upper limit to the period of peneplanation. Huntington states that in the Tian Shan a peneplaned surface "is evident in the hard Paleozoic formations and can be detected even in the soft Tertiaries." Apparently he did not give sufficient consideration to the possibility that the Tertiary areas are infaulted or inwarped blocks the present surfaces of which are merely the apparent prolongation of the surface on the older rocks, while the surface of the same age elsewhere is buried by the Tertiary sediments. The different geological chronology given by the American explorers is probably due to the fact that they found it necessary to work very rapidly and did not collect sufficient data on structural features and stratigraphy to provide a good foundation for conclusions as to age of physiographic surfaces.

Mushketov, in his publication on the Osh Hills, gives considerable attention to the problem of how the pre-Turonian (pre-Coloradoan) peneplane was produced. It might have been formed by one of four processes: (1) Sheetflood erosion. (2) Wind erosion. (3) Karst processes. (4) Normal stream erosion.

In addition, the process of marine peneplanation should also be considered.

Mushketov favors sheetflood erosion as the most satisfactory explanation, but neglects certain important features of the process. According to McGee,[1] the slopes in Sonora on which sheetflooding is active have gradients of 75–300 feet per mile. In quoting this author, Mushketov gives gradient figures of 15–20 feet per mile, but McGee states that such surfaces are formed by deposition and not by erosion. It is also to be noted that the hard rock pediments are found only at the bases of the ranges, while the centers of the valleys are filled with sand and gravel and are not subject to erosion. In its major features, including the parts beneath the valley filling, the hard rock surface is very uneven, and it is rather unlikely that a large region could be peneplaned by sheetflooding. This process is also dependent upon a delicate climatic balance with torrential storms alternating with long periods of drought. When one attempts to explain the origin of the peneplane in Fergana by this

[1] W. J. McGee, "Sheetflood Erosion," *Bull. Geol. Soc. Amer.*, Vol. VIII (1897).

process certain other major difficulties arise. The coal seams, the predominance of siliceous conglomerates, and the absence of beds of salt and gypsum in the Jurassic sediments all lead to the conclusion that the Jurassic climate of the Fergana and Tian Shan regions was fairly humid, and that organic agents and solution were active during part, at least, of the period of peneplanation.

In addition to the general improbability of desert erosion proceeding far enough to produce an even, continuous hard rock surface, the character of the Jurassic sediments shows that the climate was not favorable to processes of desert erosion.

Karst processes operate by solution and are most effective in reducing limestones. If the extensive flat limestone surfaces were produced by karst processes the slates must have stood out as remnants above them, but where Weber found the Cretaceous lying upon both Paleozoic limestones and slates the slate surface is at a lower level. Mushketov's structural sections[1] across the Osh Hills show the limestones standing out as flat uplands, while the valleys are on slates. The nature of present erosion processes indicates that the surface as now seen is probably not very different in major features from that on to which the Cretaceous sea advanced. If karst processes produced the even surfaces on the limestones, some agent must have operated later to convert the areas of upstanding slate remnants into depressions. Stream erosion might produce this result, but it is a question whether the even limestone surface would not be destroyed during the long process of stream adjustment necessary to cause the main streams to flow on the slate bands.

There are certain objections to the hypothesis of marine peneplanation. It alone will not account for the differences in altitude between the limestone and slate surfaces. The red Cretaceous conglomerates found in some places on the limestones bear no evidence of having been deposited in the sea. The oldest of the post-Paleozoic marine sediments are of Upper Cretaceous age, and these are found in some places on the flat surfaces of the Paleozoic limestones. Here the interval of time during which marine planation could have operated was very short.

[1] *Op. cit.*, Plate III.

Mushketov's objection to the explanation that the peneplane was formed by stream erosion is that the surfaces produced in this way are gently rolling surfaces upon which there are monadnocks. It seems to the writer that he has given too much emphasis to these points. The practical difficulties of field interpretation here enter. In considering the age of the surface of a block of limestone surrounded by later sediments and with an upper surface of very small area in comparison with that of its base it would be difficult to decide whether the block once had a large even top or whether it was once a monadnock with sloping sides projecting above the peneplane and since then has had its sides only slightly modified. Such hypothetical cases as this do not destroy the conception that the extensive even uplands on the large limestone areas are parts of the peneplane formed before the advanced of the Upper Cretaceous sea.

In considering the agent which produced the peneplane, the element of time enters. The land surfaces which are now being formed by erosion are the result of processes which have acted for only a comparatively short time. In the case of the area now occupied by the Fergana basin and the western Tian Shan there is a record of erosion affecting the whole region during two Paleozoic periods, the Pennsylvanian and Permian, and affecting all the area, with the exception of the local basins in which the Jurassic and the Lower Cretaceous were accumulating, during the greater part of the Mesozoic. It is quite probable that such a long interval of normal stream erosion could produce a very gently rolling surface with very few monadnocks.

GENESIS OF THE SILVER HILL TIN DEPOSITS

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ABSTRACT

Near Spokane, Washington, are some pegmatites that are unusual, not only because they contain cassiterite, but because the tin has been precipitated from a magmatic solution that is exceptionally rich in aluminum and has among its associates the minerals andalusite and sillimanite. The andalusite was precipitated first, followed by cassiterite, but the andalusite has been in part replaced by orthoclase, with which the sillimanite formed about contemporaneously, both probably the products of hydrothermal solutions which attacked the early minerals of the pegmatites. Small amounts of wolframite and scheelite occur in the pegmatites and related quartz veins, some of the veins also with galena and tourmaline. This shows the origin of pegmatites and metalliferous-bearing veins from the same parent solutions.

INTRODUCTION

Eleven miles southeast of Spokane, Washington, in Spokane County, are some tin-bearing pegmatites which are unusual because they carry the aluminum-rich minerals, andalusite and sillimanite. Small deposits of tungsten minerals and galena are in, or closely associated with, the pegmatites. All these deposits are genetically related to a magma of medium acid composition which has undergone intensive differentiation, on a miniature scale, so that almost a complete record is available within a few square miles, with submagmas as basic as kersantites and as acid as aplites and quartz veins, and with several magmas of intermediate compositions.

Though cassiterite occurring in pegmatites is not unusual, no other locality is known to the writer where it has for its associates a gangue rich in aluminum minerals. The occurrence in the same pegmatite of both andalusite and sillimanite, chemically alike, is itself quite unusual and affords an interesting study. These pegmatites also show replacement of their earlier-formed minerals by new ones while crystallization of the rock progressed, and this paper offers data on the rather recently recognized replacement that occurs in many pegmatites. The writer believes that the relationships at this place offer additional evidence on the origin and deposition

of ore minerals from magmas, and believes that the relationships illustrated here will be of rather wide interest to students of ore deposits.

The tin deposits are perhaps as rich as any in this country, but present development work has neither proved nor disproved the economic value of the deposits. The tin and its occurrence with andalusite and sillimanite have been briefly described by Collier,[1] who regards all three as primary minerals of the pegmatites.

The pegmatites outcrop on the terminus of a westward-extending spur from the Coeur d'Alene mountains of Idaho, which projects as a promontory into the Columbia Plateau. The relief is not great, and the projecting headland, known as Silver Hill because of the discovery of silver-bearing galena on its flanks, rises about 700 feet above the plateau. The spur is mature in age and is almost everywhere covered by a deep soil mantle which makes tracing of rock outcrops difficult and which effectively hid the tin deposits for many years.

GENERAL GEOLOGIC FEATURES

The tin-bearing pegmatites are only one of a number of differentiates from a granitic magma, but the others will receive scant attention in this paper, for they are only indirectly concerned with the problem of the aluminum-rich, tin-bearing pegmatites. All these rocks were intruded as dikes, apophyses, and stocks into highly metamorphosed sedimentary rocks of pre-Cambrian age which Collier[2] regards as Archean because they are more metamorphosed than the Proterozoic Belt sediments of the Coeur d'Alenes a few miles to the east which have been described in detail by Ransome and Calkins.[3]

The schistose and gneissoid rocks which the igneous rocks intrude include mica and quartz schists, quartzites, gneisses, graphitic schists, and tourmaline schists and gneisses. In these rocks the original minerals have been completely recrystallized and many new

[1] A. J. Collier, "Tin Ores at Spokane, Washington," *U.S. Geol. Survey Bull. 340*, (1907), pp. 295–96.

[2] A. J. Collier, *op. cit.*, p. 296.

[3] F. L. Ransome and F. C. Calkins, "The Geology and Ore Deposits of the Coeur d'Alene District, Idaho," *U.S. Geological Survey Prof. Paper 62* (1908).

ones have been developed. Biotite with a yellow to golden-brown pleochroism is important in most of the schists, and occurs in varying proportions in the quartzites. But the most significant feature is the almost universal occurrence of tourmaline in all of these rocks. In some the tourmaline is so abundant as to constitute a black tourmaline gneiss. This tourmaline about the intrusive rocks suggests that the magmas were rich in mineralizers, especially boron and fluorine, and that these mineralizers were responsible for the great amount of differentiation which the igneous rocks show. The mineralizers may have played an especially active part in the concentration of the tin and aluminum within the pegmatites.

Of the metamorphosed sedimentary rocks, only the graphitic schists need description, for these form either one or both walls of the tin-bearing pegmatites. These schists are rich in aluminum silicates, and this may have some bearing on the source of the aluminum in the pegmatites. The graphitic schists are spotted with pinkish crystals of andalusite much like those in the pegmatites, except that the andalusites in the schists are crowded with graphite inclusions, whereas those in the igneous rocks are free from included matter. The crystals of andalusite in the graphitic schists range in size from minute needle-like crystals to rod-like forms over an inch long. A few have their longer diameter parallel to the schistosity, but most of them occur in rosettes which have no definite relationship to the schistosity. The crystals have a marked pink pleochroism—deep pink in the center with an almost colorless zone surrounding. Usually they have a black core of graphite which in basal sections shows ill-defined crosses. This is shown by Figure 1. They are also surrounded by a dense black zone of graphite which represents excess carbon crowded aside during the crystallization of the andalusite. A few crystals of tourmaline are present as inclusions in the andalusite, and indicate that some, or possibly all, of the tourmalization preceded the development of the andalusite crystals.

Little need be said of the structure of the sedimentary rocks except that they have been complexly folded, and in many places the original bedding has been entirely destroyed by the metamorphism. Igneous structures will be considered later.

IGNEOUS ROCK TYPES

To show the relation of the tin-bearing pegmatites to the other igneous rocks of the area a brief summary of the various differentiates will be given. The differentiation is remarkable for the miniature scale on which it is displayed. The differentiates include bodies of quartz diorite, quartz monzonite, granite, and granite pegmatite,

FIG. 1.—Basal sections of andalusite (*A*) in graphitic schist showing graphite inclusions and dense enveloping zone of graphite. Medium power, uncrossed nicols.

and dikes of kersantite, aplite, and tourmaline-bearing pegmatite in addition to the tin-bearing dikes and quartz veins. The locations of the tin-bearing bodies and the larger igneous masses are shown on the map (Fig. 2), but many of the dikes were too small to show, and were left undifferentiated from the sedimentary rocks.

The oldest igneous rock is a quartz diorite which appears as a prominent border phase of the main intrusive batholith. Apophyses of this rock are common in the sediments. It is a fine-to-medium-grained, granular, dark-gray rock with dark and light minerals in about equal quantity. In some places at the contact with the sedi-

mentary rock the diorite merges into a dark basic phase composed mainly of greenish hornblende with subordinate quartz. Hornblende is the predominating black mineral of the quartz diorite with biotite

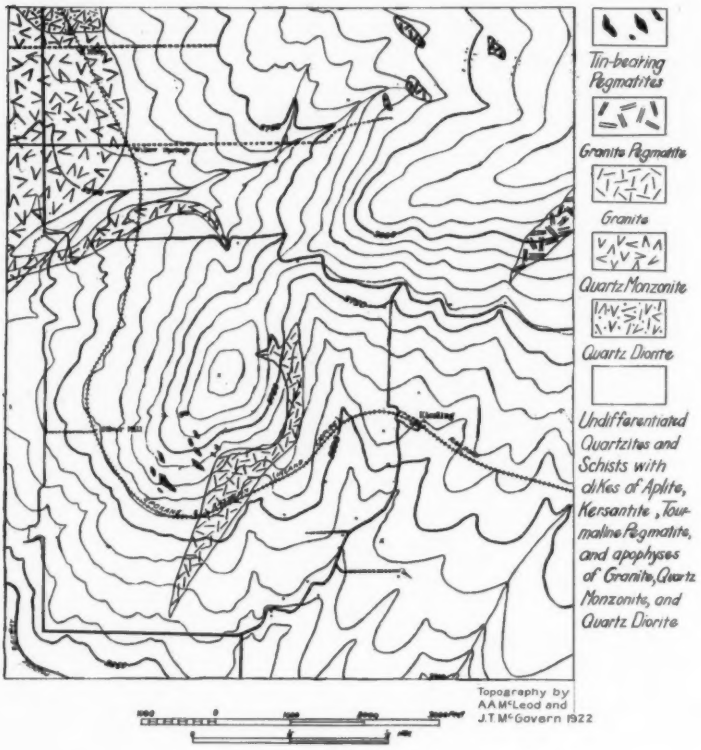
Tin-bearing Pegmatites
Granite Pegmatite
Granite
Quartz Monzonite
Quartz Diorite
Undifferentiated Quartzites and Schists with dikes of Aplite, Kersantite, Tourmaline Pegmatite, and apophyses of Granite, Quartz Monzonite, and Quartz Diorite
Topography by A.A.McLeod and J.T.McGovern 1922

FIG. 2

subordinate. These minerals occur in clusters, the hornblende usually intergrown with the biotite. The plagioclase is highly zoned, with the average composition of andesine. Orthoclase is accessory. In some of the rocks the quartz becomes more abundant than plagioclase. The texture is hypautomorphic granular. A yellowish-brown accessory, tentatively identified as xenotime, is abundant in many places in the quartz diorite as well as in the quartz monzonite bodies.

The bodies of quartz diorite grade inward into quartz monzonite, passing through a granodiorite stage, but this intermediate type is not abundant. The quartz monzonite also sends apophyses into the diorite. Petrographically the two types are similar and differ only in that in the quartz monzonites biotite becomes more abundant than hornblende, and orthoclase equal to the andesine.

Normal granite is confined to one small stock. The rock is generally coarse-grained, pinkish in color, and in many places grades into a graphic granite or granite pegmatite. This type is considerably more acid than the others, and the only dark mineral is biotite, which is much less abundant than in the older types. Quartz is most abundant, but is closely followed by microcline and lesser amounts or orthoclase and oligoclase. Accessory apatite, ilmenite, and titanite are present in the granite and in the older types.

Granite pegmatite with biotite as the ferromagnesian mineral and with muscovite, microperthite, quartz, orthoclase, and subordinate oligoclase as the light minerals, is abundant in the region. These form large dikes cutting the sediments, or form phases of the granite. The pegmatitic bodies show much variation in texture, from coarse-grained granitic to graphic. The latter is characteristic. Though this variety of pegmatite is abundant over a wide area, tin has not been found in it.

Aplites are particularly abundant. These range from dikes an inch or two in width to those three or four feet wide. Many of the dikes are branched and produce a network so that large areas are composed mainly of this rock type. These aplites cut bodies of the granitic rocks, including pegmatitic phases. Many show a gradation into graphic granite, and thus an obvious relationship is established between the two. On the other hand, there appears to be a gradation into the younger and more acid tin-bearing pegmatites, because in one place a typical aplite was found which contained a segregation of andalusite and sillimanite, characteristic gangue minerals of the tin-bearing pegmatites. Thus the granitic pegmatite appears to change to younger aplitic types, and the aplitic in turn to younger tin-bearing and tourmaline pegmatites. The aplites are normally fine-grained and sugary in texture. Small amounts of biotite and muscovite are present, but the content is variable and some

dikes carry little or none. Muscovite usually predominates over biotite. Quartz is slightly more abundant than the orthoclase, and both have allotriomorphic forms, and in some sections show a slight micrographic intergrowth. Accessory oligoclase and microperthite are present in some.

The tourmaline pegmatites are unlike the granite pegmatites and differ to a lesser degree from the aplites. These are similar to the more basic aplites, and the relationships observed suggest transitions between the granite pegmatites, the aplites, and the tourmaline pegmatites. These pegmatites also show their relation to the tin-bearing pegmatites, for a typical tourmalinic phase in one end of a large pegmatite was observed to merge with the tin-bearing phase. The tourmaline phase of the tin-bearing pegmatite is composed largely of sodic feldspar, with oligoclase predominating and with subordinate microperthite and orthoclase. The tourmaline occurs in fractured rounded masses and somewhat resembles the cassiterite, though black. Scattered foils of muscovite are present, and usually small amounts of apatite. In one dike which occurs outside of the tin-bearing area, black, barreled-shaped tourmaline crystals one to two inches long are the only dark minerals and give the dike a peculiar spotted appearance. Here the feldspar is dominantly orthoclase with subordinate oligoclase and microperthite.

Several lamprophyre dike occur in the district. Their age is not well established, but they are older than the tin-bearing pegmatites, for they are cut by seams of the latter and are also cut by the granite. They are probably related to the quartz diorite, though no dikes were found in the diorite masses. Collier[1] tentatively ascribed the lamprophyre to the variety kersantite, being composed predominantly of biotite and plagioclase, with lesser amounts of hornblende, augite, and olivine. The hand specimen is dense, microcrystalline, black with a decided purplish tint, and has a few recognizable flakes of biotite.

The field relationships, as well as the petrographic studies, show that the tin-bearing pegmatites are one of a number of closely related differentiates from a parent magma. Three varieties of pegmatite are represented, but only one carries cassiterite along with

[1] A. J. Collier, *op. cit.*, p. 297.

minerals not found in any of the other pegmatites—the andalusite and sillimanite. The tin-bearing pegmatite shows other differences, which lead one to believe that the conditions responsible for the concentration of the cassiterite and aluminum minerals are unique.

THE TIN-BEARING PEGMATITES

The tin-bearing pegmatites have been found only in a small area on the headland of Silver Hill, facing south, and number about a dozen lenticular dikes intruded into a patch of andalusite-bearing graphitic schists, quartz and mica schists, and a few apophyses of gneissic quartz monzonite. The largest dike is 200 feet long; it has a maximum width of 25 feet, pinching at the ends. The average width is about 10 feet, and the dip about 45° to the west. This occurs lens-like between a hanging wall of gneissoid monzonite and a footwall of quartz, mica, and graphitic andalusite-bearing schists. Other dikes range down to a dozen feet in length. Shoots of cassiterite have been uncovered in three or four, but the typical andalusite-sillimanite gangue is shown in the bared surface exposures of all.

STRUCTURE OF THE DIKES

The structure of the pegmatite is not uniform throughout, but there has been a differentiation or segregation within the dike, producing two distinct phases, one the pegmatitic phase proper, which occurs along the footwall and contains the cassiterite, sillimanite, andalusite, orthoclase, and other pegmatitic minerals, and the other a quartzose phase which in some places contains nodules of scheelite and wolframite. This relationship is illustrated in Figure 3, which is a sketch made down an incline that was sunk along the dip of the largest and most important pegmatite to a depth of over 100 feet. The pegmatitic phase is unevenly segregated along the footwall, in some places occupying the greater portion of the dike and in others giving way to barren quartz, suggesting that the minerals which make up the pegmatitic phase, because of their greater specific gravity and relative insolubility, have settled from a highly aqueous siliceous solution leaving quartz with a few nodules of the apparently more soluble tungsten minerals to occupy the remainder. Below the 100-foot level the pegmatitic phase is entirely displaced and the

vein is occupied by quartz which contained large nodules of tungsten minerals. On the 100-foot level a drift has been run to the north approximately 175 feet and follows partly through barren quartz and partly in the pegmatitic phase, which in some places contains notable amounts of cassiterite. The tin-bearing pegmatite is thus of irregular form, and the tin is not uniformly distributed through it. These dikes seem to illustrate the process of gravitative differentiation on a miniature scale and show the origin of pegmatites and

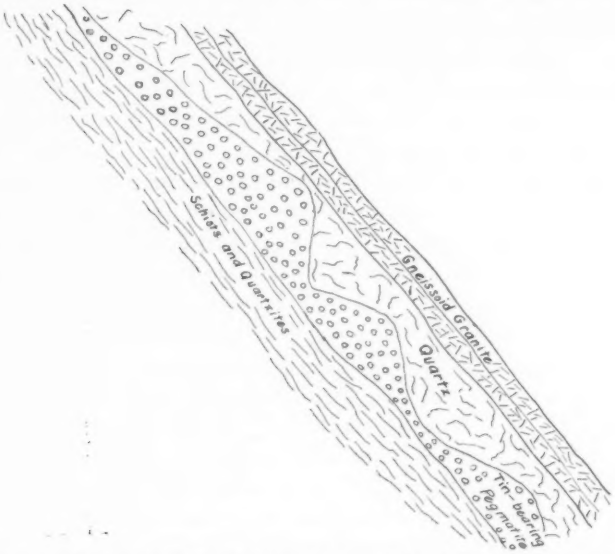

FIG. 3.—Section along dip of tin-bearing pegmatite showing segregation into a tin-bearing pegmatitic phase along the footwall and a quartzose phase along the hanging wall. Some tungsten nodules occur in the quartzose phase. Adapted from Collier.

quartz-dikes from the same parent solution. Small dikes of the quartz phase intrude the sediments as quartz veins or dikes and also intrude the pegmatitic phase in places as narrow seams. Cassiterite has been found only in the pegmatitic phase.

TEXTURE OF THE PEGMATITIC PHASE

The tin-bearing phase is different in appearance from any of the pegmatites in the district and is easily recognized by slight

tinges of pink and pinkish crystals in a nearly white-to-gray, fine-grained mass with felted texture and in which are usually embedded nearly black grains of cassiterite from the size of a pin head to masses several inches in diameter. The flashes of pink are quite characteristic and easily serve to distinguish this type from the others, even where cassiterite is lacking. The pinkish tinges are due to ill-defined masses of andalusite which have been partially replaced by orthoclase. In some parts of the pegmatites the andalusite has distinct crystal outlines, and here the pink crystals are slender rod-like forms up to one inch in length. These are scattered and are less abundant than the partially replaced crystals in which the pinkish color merges into white or gray.

The peculiar and distinctive felted texture which characterizes this phase is due to minute needles and bundles of needles of sillimanite which usually form radiating aggregates. The needles are usually white, but the grayish color of some is due to minute flakes of graphite. The orthoclase cannot be recognized except microscopically, because it is so intimately associated with and overshadowed by minute sillimanite fibers. Muscovite is sparingly distributed through the mass in small isolated flakes or patches and generally in the highly siliceous portions of the pegmatitic phase. Tourmaline is present in but a very few places and is entirely wanting in most of these deposits, except where locally the pegmatite merges into a phase with a different composition. Graphic texture is wholly lacking.

The cassiterite is without definite crystal outline and is distributed through the pegmatitic phase in granules which have been fractured and cemented by the gangue materials. The cassiterite, in some of the dikes, occurs in general near the central portions of the pegmatitic phase and suggests that at the time of its crystallization the magma was too viscous to allow a settling under gravity and segregation along the footwall. Some parts of the dikes carry as much as 10 per cent cassiterite, but the average is much nearer 2 per cent.

The gangue minerals in the order of their abundance are sillimanite, quartz, orthoclase, andalusite, muscovite, and accessory graphite. The quartz content is variable, being either greater or less than the other minerals. All masses of the pegmatite grade into bodies of nearly pure sugary, granular quartz.

MINERAL RELATIONSHIPS

The minerals of the pegmatite show not only normal crystallization from solution, but also replacement of some of those first formed. These deposits offer additional evidence that replacement in ore deposits is not confined to veins alone, but can occur in pegmatites as well. The general sequence of crystallization beginning with the earliest is andalusite, cassiterite, muscovite, orthoclase, sillimanite, muscovite and quartz. Considerable overlapping occurs with some of the later minerals.

Replacement of andalusite by orthoclase.—Microscopically, the andalusite is characterized by a marked pinkish pleochroism usually most strongly pronounced in the center of the crystal. A few crystals have perfect sections, being slender, rod-like, with square basal sections characterized by a good prismatic cleavage, but by far the most of them are partially to almost wholly replaced by orthoclase and have indefinite outlines. Some crystals have rounded outlines. The contact between the andalusite and the orthoclase is generally sharp, but some have a tendency to merge, and the orthoclase boundary has a somewhat different extinction from the rest of the orthoclase crystal. Many show the result of corrosion where crystals have been more or less unevenly replaced. But even more common are detached, rounded grains of andalusite, engulfed in the orthoclase, remnants of former large crystals where replacement took place along cleavage lines in the andalusite. These "islands" are perfectly oriented crystallographically, with the main andalusite crystal. Such an example is illustrated in Figure 4, where several isolated grains and rods in orthoclase are in perfect orientation with each other and with their parent crystal. In some sections only tiny rounded grains remain from former large crystals.

Many andalusite crystals have a rim or border of muscovite. This zone of mica is always narrow and shows distinctly a fraying or merging of the andalusite into the mica, as though potash-bearing solutions reacted with the aluminum silicate to form the less aluminum-rich mica, or that the potash solutions extracted aluminum from the andalusite to form the muscovite. The mica is found only where the andalusite has been slightly affected, and where replacement has progressed farther, orthoclase forms instead. Appar-

ently the potash solutions in many places extracted more than enough aluminum to form the orthoclase. This is very significant, for it shows some of the chemical reactions involved in the replacements of these pegmatites.

The cassiterite.—The cassiterite is clearly older than the orthoclase, sillimanite, quartz, and muscovite, for fractures in the cas-

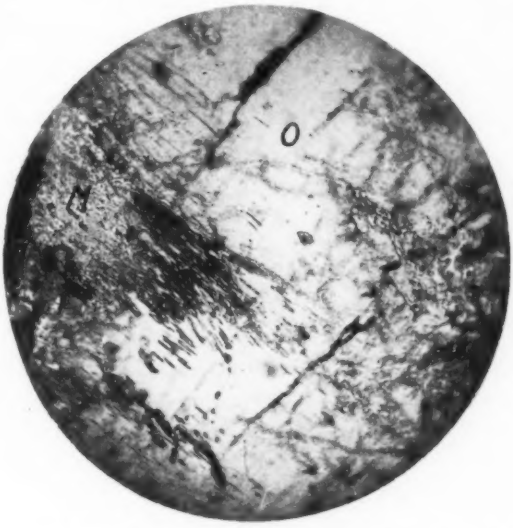

FIG. 4.—Orthoclase (*O*) crystal showing penetration by some sillimanite (*S*) needles. The sillimanite merges with muscovite (*M*). Crossed nicols.

siterite crystals have been filled with these minerals. No andalusite could be found in any of the fractures, and it is likely that the andalusite crystals rendered the magma more or less rigid and prevented a gravitative segregation of the cassiterite. This would explain the position of the tin near the central portion of the pegmatitic phase. The cassiterite is subtranslucent in brownish tones and has no inclusions, but borders have a somewhat bleached appearance.

The orthoclase.—The orthoclase is generally abundant. The crystals are always anhedral. Some crystals surround oriented, rounded, and corroded grains of andalusite poikilitically, and indicate that

the potash-bearing solution was dissolving the andalusite when the orthoclase crystallized. The orthoclase crystals are clear and have few inclusions except liquids and gases. The slight change in composition about some andalusite grains has already been remarked. A surprising feature is the apparent lack of any other feldspar. This pegmatite thus shows a marked chemical difference from the other pegmatites in which plagioclases are important and the presence

FIG. 5.—Bundles of sillimanite (*S*) needles in a fine mosaic of orthoclase (*O*). Crossed nicols.

of only potash feldspars in these tin-bearing pegmatites is probably significant.

Relation of sillimanite and muscovite to orthoclase.—The sillimanite is probably about contemporaneous with the orthoclase and developed along with most of it, though carried into later stages: Long needle-like crystals are most common, occurring singly or in bundles. The latter are most characteristic and are illustrated in Figure 6. The needles penetrate the orthoclase, and an individual needle may penetrate as many as three orthoclase crystals. The needles show no indication of having been formed as the result of

alteration of the feldspar, but appear to have developed more or less contemporaneously with the orthoclase. This indicates that at the time of crystallization of orthoclase the magma had an excess of aluminum which crystallized as sillimanite. That the sillimanitization process carried into the quartz stage is shown by a penetration of sillimanite needles into the quartz crystals in some places. The larger crystals of sillimanite have a marked prismatic cleavage. The crystals are colorless.

Many of the sillimanite bundles and partially replaced andalusites extinguish together, though separated by orthoclase, which suggests that the sillimanite developed within the borders of the original andalusite. These needles do not represent a replacement of the andalusite by sillimanite, but probably represent the excess aluminum above that needed to form the orthoclase which had been extracted by the potash solutions from the andalusite. Sillimanite is the most abundant mineral, but an interesting relationship was observed with respect to the andalusite in that where andalusite is abundant and only slightly corroded, sillimanite is a minor mineral, but where the andalusite has been largely dissolved or replaced, sillimanite is the predominant mineral. *This would indicate that the amount of sillimanite is in some way controlled by the amount of andalusite, and their ratio varies inversely.* Some sillimanite needles stop against andalusite crystals, but nothing indicates that the andalusite changed directly to sillimanite.

Muscovite appears to be present in two generations, though there may be considerable overlapping. The earliest stage is the border zone around some of the andalusite crystals, which has already been described. This occurs where sillimanitization is but poorly started, and the more andalusite present, the greater the amount of the muscovite, but the mica is always quite subordinate. Flakes are microscopic. The other generation is in the more quartzose portions of the pegmatitic phase, and appears to be somewhat contemporaneous with the sillimanite, for some crystals fray into sillimanite. Penetration of orthoclase by sillimanite needles and the merging of the needles with muscovite is illustrated in Figure 5. Some flakes of mica occur in the quartz, and these are evidently younger than all the minerals except the quartz. All flakes are small,

few being over one-half inch. It seems likely that in some parts of the pegmatite the mica formed between the andalusite and orthoclase where the potash content was still relatively low; but where the potash content was high, orthoclase developed along with or closely followed by sillimanite, and in some parts the ex ess alumi-

FIG. 6.—Crystal of andalusite (*A*) partially replaced by orthoclase (*O*). Note the isolated remnants of the andalusite crystal and the needles of sillimanite (*S*) on the sides. Crossed nicols.

num retained sufficient potash to form the muscovite of the younger generation. Some overlapping of all these processes occurred.

Accessories.—A little apatite has been reported. Graphite is sufficiently abundant in some of the dikes to give the gangue a grayish color, and locally small spots may faintly mark porcelain. Flakes are microcrystalline and generally occur between the sillimanite needles which make up the bundles. The graphite is probably derived from the schists into which the pegmatites are intruded. It is not present in all dikes.

ABNORMAL CHARACTER OF THE TIN-BEARING GANGUE

Cassiterite is by no means an uncommon mineral in pegmatites, but in no other place known to the writer does it occur in association with andalusite or sillimanite.[1] Both of these aluminum silicates rarely occur in igneous rocks, but both are essentially minerals of slates or schists formed under conditions of intense metamorphism. According to Vogt,[2] aluminum, potassium, and sodium are relatively subordinate in tin deposits. The occurrence of the aluminum-rich minerals andalusite and sillimanite associated with tin, and especially in such large quantities, is therefore unique. The development of both andalusite and sillimanite, which have the same chemical composition but somewhat different physical properties, and the crystallization of the sillimanite in the later stages of formation of the dike minerals after crystallization of the andalusite offer a perplexing problem which has not been found in any other place. As sillimanite has the higher density and commonly forms under the more intense condition of temperature and pressure, its development in the later stages suggests a reversal of ordinary conditions of the mineral deposition, due perhaps to increased pressures attending the hydrothermal phase which brought in the potash solutions.

The tin-bearing pegmatites differ from the others in the district in the chemical nature of the feldspars. In these dikes only orthoclase is present, but some plagioclase occurs in all the other types.

These pegmatites clearly represent deposits exceptionally rich in aluminum. They represent concentration of aluminum as the silicate differing from most such magmas where the aluminum precipitates out as the oxide, corundum. It is not likely that the aluminous minerals were formed by replacement of the andalusite-bearing graphitic schist of the walls. The pegmatites show no indication of wall replacement, for contacts are sharp and no partially assimilated wall segments are present in the dikes. Hydrothermal

[1] Collier also regards these minerals as primary.

[2] J. H. L. Vogt, "Magmas and Igneous Ore Deposits," *Economic Geol.*, Vol. XXI (1926), No. 4, p. 320.

alteration is lacking. The schistosity of the wall-rocks curves about the dikes. The aluminum is an original component of the tin-bearing pegmatites, as the field and microscopic studies show. It may be possible that the aluminum was derived from engulfed and assimilated argillaceous rocks If such were the case, other types of pegmatites might be expected to show a high aluminum content, but none of them do. Although, according to Vogt,[1] aluminum is an element which, as a rule, is extracted only in small quantities or not at all by the volatile compounds acting on magmas, the fact that the tin has been found only in association with the andalusite and sillimanite gangue suggests to the writer that the same conditions which caused the magmatic concentration of tin from the granitic intrusives also caused the concentration of aluminum. What these conditions are would be difficult or perhaps impossible to postulate, though the presence of the rich tourmaline aureole in the sediments suggests that boron and fluorine may have been active.

RELATION OF TIN-BEARING PEGMATITE TO THE SCHEELITE, WOLFRAMITE, AND GALENA DEPOSITS

Several quartz veins crop in the vicinity of the tin-bearing pegmatites. These veins have the same granular, sugary appearance as the siliceous phase of the pegmatites, and, like the siliceous phase of the pegmatites, carry a few small nodules of the tungsten minerals scheelite and wolframite. These veins are quite obviously related to the same magma which produced the tin-bearing pegmatites, representing a later stage of the differentiation when temperature conditions were perhaps lower.

Similar small siliceous veins have yielded unimportant amounts of silver-bearing galena. The galena is associated with a brownish tourmaline gangue which indicates a hypothermal genesis. The galena probably precipitated upon further cooling of the aqueo-igneous solution from which the cassiterite and tungsten minerals had already been deposited. Any further record of mineral deposition has been lost through erosion. It is possible that these are the roots of former eroded veins that reached far above the present surface. As the quartz monzonite which is present in this area is thought to

[1] J. H. L. Vogt, *op. cit.*, No. 5, p. 495.

be related genetically to the batholith which underlies the Coeur d'Alene region, and as the Coeur d'Alene deposits are believed to be associated with the intrusion, it is likely that the mode of occurrence and the general relationship of the sulphides in this district may throw some light upon the genesis of the deposits in the Coeur d'Alenes.

CONCLUSIONS

The tin-bearing pegmatites are one of a number of differentiates from a parent magma of medium acid composition. These pegmatites are not only unusual because they carry cassiterite, but also because they are remarkably rich in aluminum in the form of andalusite and sillimanite, both of which are regarded as primary constituents. These pegmatites are unlike any of the others in the area, and it seems likely that the conditions responsible for the concentration of the tin from the granitic intrusives also caused the concentration of the aluminum.

Andalusite crystallized first from the aluminum-rich solution and probably rendered the dike mass sufficiently rigid to prevent a gravitative segregation of the cassiterite which precipitated soon after. The partially crystalline pegmatite was then invaded by hydrothermal solutions, probably under increased pressures and temperatures, which caused a fracturing of the cassiterite. The invading solutions were rich in potash, and in this new environment the andalusite was soluble and the potash dissolved the aluminum needed for the formation of orthoclase. This caused partial to entire solution of the andalusite crystals with the orthoclase, replacing either along cleavage lines or working inward from the borders. In some parts of the pegmatites the potash was probably not sufficiently concentrated to produce orthoclase, and muscovite, with its greater content in aluminum, formed as a border about the andalusite crystals. Then perhaps, due to changed physical and chemical conditions, the aluminum was in excess, and when crystallization of the orthoclase occurred the dissolved additional aluminum precipitated as needles and bundles of needles of sillimanite intergrown with and penetrating the orthoclase, and occasionally with some of the early-formed quartz. In some places, and especially in the more quartzose parts, the excess aluminum retained some potash

and crystallized as muscovite of the younger generation. That the sillimanite has developed at the expense of the andalusite is shown by the relative abundance of the two minerals, for where andalusite shows but slight replacement, both orthoclase and sillimanite are minor, but where the andalusite has been largely replaced, the orthoclase, and especially the sillimanite, show the greatest abundance.

An apparent gravitative differentiation within some of the pegmatites has caused the cassiterite with its peculiar aluminous gangue to segregate along the footwall, whereas the upper portion is composed of granular quartz with a few nodules of tungsten minerals which send small quartz veins into the bordering rocks. Some of the quartz veins also contain nodules of tungsten minerals, and several contain small masses of silver-bearing galena associated with a tourmaline gangue. This shows the origin of pegmatites and metalliferous-bearing quartz veins from the same parent solutions.

ACKNOWLEDGMENTS

The writer wishes to express his gratitude to Dr. F. B. Laney, of the Department of Geology at the University of Idaho, under whose direction the field work was done, for valuable counsel in the laboratory studies and in the preparation of the report. Acknowledgment is also due Dr. E. S. Bastin, of the University of Chicago, for suggestions in the preparation of the manuscript, and to Dr. A. Johannsen for aid in the microscopic determinations. To them the writer desires to convey his thankful appreciation. The base map was prepared by A. A. McLeod, a student at the University of Idaho, with the aid of Dr. Laney as a part of the requirement for a Bachelor's degree, and through their courtesy the map was made available to the writer.

RESPONSE TO REVIEW OF "ERUPTIVE ROCKS"

I hope the editors of the *Journal of Geology* will permit me to reply to a few of the points raised by Professor Johannsen in his review of my book, *Eruptive Rocks*, in the January number of the *Journal*. I only ask permission to clear up misunderstandings and to correct statements which convey a wrong impression of the purpose of my book and of the utility of the proposed classification.

In the first place, let me say that my book was never intended to provide a summary of everything that has been written about eruptive rocks. It is addressed more particularly to active workers in petrology, with the object of bringing my method of classification to their notice, and I have assumed that they are as well acquainted with the general literature of the subject as I am. Hence the absence of any reference to Niggli's widely known work; hence, also, my silence regarding Professor Johannsen's own important contribution to the quantitative mineralogical classification of rocks. I did not seek to "give the impression that no quantitative mineralogical system had ever been proposed before"; I simply was not concerned with the historical aspect of the matter at all.

Coming now to details of my proposals, Professor Johannsen says that in 1916 I proposed twelve groups on the basis of the "color index," and that I have now reduced the twelve groups to four. This is a curious example of misunderstanding. All that I did in 1916 was to suggest a simple way of indicating the color index of a rock by means of a prefix; this was not a proposal for a *classification* of rocks, and it is not in conflict with anything that I have proposed since.

Professor Johannsen is mistaken in thinking that the "color index" is defined in terms of proportions by weight; it is clearly defined in terms of volume, for the reason that proportions by volume are easily ascertained by the micrometric method. In quoting modes from other writings I have taken the authors' figures as I found them, but when weights are given instead of volumes I have generally indicated this.

In discussing my proposal to use the molecular proportions of Or, Ab, and An in place of the indefinite orthoclase and plagioclase, Professor Johannsen says that "in a mineralogical classification one is not concerned with the proportions of the potash, soda, and lime molecules in the rock." But I have not proposed to classify rocks by the proportion of potash, soda, and lime in the rock; I have proposed to classify them

by the proportions of orthoclase, albite, and anorthite in the felspar, which is a totally different matter. I have tried, in fact, to apply in an exact way a factor which Johannsen, Iddings, Rosenbusch, and others use in an inexact way. My system does not cease to be a mineralogical one because I employ an accurate instead of an inaccurate statement of the composition of the felspar!

Finally, Professor Johannsen makes a statement to which I must take particular exception, since it conveys a totally wrong impression of my whole method and principle of classification. He says: "In a combined system, such as that given by Shand, one should have not only a chemical analysis of the whole rock but chemical analyses of the individual components as well." It would hardly be possible to give a more misleading account of my method than this. My system is not a combined one; it depends on purely mineralogical data to exactly the same extent as Professor Johannsen's own system. Most rocks which are not too minutely or incompletely crystallized can be classified by my system without any chemical analysis at all. It is only when the ratio of Or-Ab-An in the felspar approaches the limiting values of 1:1 or 3:1 that a chemical examination of the *felspar alone* may be necessary; and even in such cases it is often possible to reach a fairly accurate conclusion regarding the composition of the felspar by the careful combination of optical data with specific gravity and with simple qualitative tests such as Szabo's flame reactions and ordinary microchemical tests.

But I do indeed maintain that although "microscopy is the primary method of petrography, chemical analysis is the secondary method, and what a petrographer cannot learn by one method he must be prepared to ascertain by the other." Until this minimum requirement is accepted by petrographers I can see no future for petrology.

S. J. SHAND

REVIEWS

The Geology of Mongolia. Natural History of Central Asia. Vol. II. By CHARLES P. BERKEY and FREDERICK K. MORRIS. New York: American Museum of Natural History, 1927. Pp. xxv +475, 4to; figs., 161; plates, 44; colored maps, 6. $10.00.

Once in a while a great step forward in our knowledge of some large and important far-away section of the globe is made as the outcome of the comprehensive, correlated work of a great expedition. The scattered fragments of pre-existing geologic knowledge of the region then give way to the systematic treatment of the outstanding problems from a broad point of view which makes the published results at once the standard treatise on the region. A notable work of this sort has recently appeared.

This splendid volume is based on five thousand miles of *reconnaissance* exploration in Mongolia made by the authors during the field seasons of 1922 and 1923, as members of the American Museum's Central Asiatic Expeditions. The route traversed extends from Kalgan to Urga, to Tsetsenwan, to Sain Noin, to Gorida, to Uskuk, to Tsagan Nor, to the Baga Bogdo and Gurbun Saikan ranges of the Altai Mountains, and back through Shabarakh Usu, Sair Usu, Ardyn Obo, and Shara Murun to Kalgan. Throughout the entire extent of this traverse, geologic cross-section profiles were constructed en route, and these, appearing in the text in large numbers, are among the particularly valuable contributions; detailed topographic and geologic maps were made where the party camped a week or more.

Mongolia embraces a great interior desert basin, the Desert of Gobi, encompassed by high mountains with the drainage inland. Granite and graywacke rocks come to the surface and extend in every direction for great distances. Upon this complex of old rocks an extensive erosion surface and shallow sediment basins were developed. It is in the sedimentary and eolian deposits of these sediment basins that the remarkable fossil finds have been made.

The pre-Cambrian of Mongolia comprises three main divisions: the Tai Shan complex (Archean), Wu Tai system (early Proterozoic) and Khangai or Nan Kou system (late Proterozoic). At some undetermined time after the Khangai, which is strongly folded, but before deposition

of the later Paleozoic sediments, came the greatest igneous invasion recorded in Mongolia—the "great Mongolian batholith"—which in horizontal spread compares favorably with the greatest batholiths thus far known in other parts of the world.

An unconformity stands for the first half of the Paleozoic, followed by marine beds of late Paleozoic age. The rocks are all closely folded, but the fossil content is fairly well preserved. Striking indeed is the fact that all sedimentary deposits after the close of the Paleozoic thus far found in central Mongolia are of continental type. Since Permian time this portion of the continent has never been resubmerged. Jurassic beds, reaching an estimated maximum thickness of 20,000 feet, complete the formations of the "old-rock floor."

Above the Jurassic is the most important single structural feature of the region, the unconformity between the folded strata of Jurassic and older age, which together make up the complex old-rock floor, and the nearly flat-lying sediments of Cretaceous and younger age, which lie above this floor. The hiatus is so extensive that mountain building and erosion of thousands of feet of material were accomplished before the first basin sediments were laid down. During this interval an entire change in the diastrophic habit of north central Asia came about. Mountain folding characterized the deformation that took place before that time, whereas warping and block faulting, without mountain folding, characterize subsequent epochs.

In general the present-day mountains of Mongolia are of two types: the fault bock, which owes its relief to direct uplift or tilting, and the eroded arch. Although the internal structure of the fault-blocks is as complex as the old-rock floor, and includes folded rocks, the mountains themselves are not fold mountains. The other type of mountain is the result of the erosion of great upwarped arches. They have been raised to such elevations and have persisted sufficiently long for erosion to have carved mountain relief on them.

The "Gobi erosion plane" appears as a series of wide stretches of wonderfully smooth country, sloping very gently except where recently deformed. Both horizontal and tilted strata are beveled to almost equal smoothness. Of comparatively recent origin, overlying all the sedimentary formations, including the latest Pliocene or earliest Pleistocene, yet this plane is being destroyed, not formed, in the present epoch—which indicates that it was formed under somewhat different climatic or other conditions than those of the present time. An earlier erosion surface of considerable extent is called the Mongolian peneplain.

The value of this excellent synthesis of the geology of such an important portion of our greatest continent will be at once apparent to the student of the larger problems of our science, as well as to every geologist seeking information on the heart of Asia. A great deal has been accomplished by these costly expeditions, and the results are here set forth most admirably. Printed in large type and handsomely illustrated, the volume is very attractive. An extensive bibliography appears at the end.

R. T. C.

Geologie von Sibirien. By W. A. OBRUTSCHEW. Berlin: Gebrüder Borntraeger, 1926. Pp. xi+572; plates, 10; text figures, 60; geological map.

The interest which is now shown in Germany for the geology of Russia, particularly the economic geology of Russia, has produced a number of publications like Bubnoff's *Die Kohlenlagerstätten Ruslands und Sibiriens* and others, most important among which is *Geologie von Sibirien*, by Obrutschew, which was published as No. 15 of Soergel's series, *Fortschritte der Geologie und Palaeontologie.*

The book is divided according to the geologic formations, but has an introductory chapter dealing with the geomorphism of Siberia. There is a concluding chapter about the structural history and tectonics of Siberia. The work had been concluded in manuscript in January, 1925, and the literature which appeared between the completion of the bulk of the manuscript and the date of the foreword, November, 1925, is treated in an appendix of fifty pages.

Great care has been taken to include all available literature and a great deal of information which was supplied by individuals. These facts make the book the most up-to-date and complete treatment of the geology of Siberia in a language other than Russian. It makes it a great deal easier for the regional and structural geologist to study this rather difficult subject, because it saves him the trouble of having numerous Russian publications translated into English.

The great importance of the economic development of U.S.S.R. makes a book dealing with the geology of Siberia of particular interest because Siberia contains the greatest mineral resources of the U.S.S.R. and has in its territory, which is a great deal larger than the United States and Canada combined, untold and largely unknown deposits of coal and iron, non-ferrous metals, and petroleum. The Kusnetz basin of Siberia represents the largest known coal field of U.S.S.R., and with the development

of industries will attain great importance in the economic life of Siberia and Russia.

The amount of information which is available about Siberia is large. Most of it has been brought to light by the Geologic Committee of the U.S.S.R. at Leningrad, which is the name of the Russian geological survey corresponding in its functions to the United States Geological Survey in Washington. It may be added that the Geologic Committee of the U.S.S.R. is the largest institution of it kind, having a permanent staff of over one thousand persons, to which are added three thousand more during the field season.

Not only stratigraphy, but also the paleontology, has received careful attention in this book and its paleontologic part pays attention to invertebrate faunas as well as to fossil floras; but owing to the comparative newness of the terrain, very little is known about fossil vertebrates.

The illustrations are well executed, but not very numerous, and a larger number of them would undoubtedly have been desirable. There are a number of interesting correlation tables in the book, and it is noteworthy that the author has tried to compare as closely as available information permitted the Siberian deposits with those of Europe.

The book will prove a very valuable source of information, not only for the regional geologist, but also for the structural, economic, and stratigraphic geologist, as well as for the paleontologist. The reader cannot fail to be impressed by the prospects of the enormous amount of geologic information that can be obtained from Siberia and will in still larger quantities be obtained from the interesting and only partially explored enormous territory of the U.S.S.R., the biggest single country on the face of the globe.

A. C. N.

A Laboratory Manual of Dynamic and Structural Geology. By KIRTLEY F. MATHER and RALPH G. LUSK. Cambridge: Harvard University Press, 1926. Pp. vii+103; also a supply of special forms for laboratory reports.

In a field so unsettled as that of laboratory work in general geology no apology is needed when a new laboratory handbook makes its appearance; and this is especially true when the book in question is so well organized and so full of interesting and suggestive innovations as the manual by Mather and Lusk. Although designed primarily for the introductory course in physical geology at Harvard, it is bound to exert an important influence in many other institutions.

The Introduction acquaints the student immediately with the essential facts regarding the organization of the entire course—lectures, laboratory work, field trips, library readings. Thus at the very outset, and indeed throughout the manual, the unity of the course is made clear. An incidental feature in the Introduction is a few paragraphs of suggestions on note-taking, constituting one of the most effective summaries of this difficult subject that the reviewer has ever met with.

The manual includes ten laboratory exercises and two special assignments. The first three exercises deal with minerals and rocks, with descriptive matter carefully tabulated, and with blanks to be filled in by the student when making his determinations. While the student is engaged in this work in the Laboratory, he is also studying the first special assignment independently. This assignment is an introduction to topographic maps, correlated with the first field trip and utilizing the map employed on that trip; and it also includes a well-organized introduction to the construction of profiles.

The last seven exercises cover the usual geologic processes: gradation by water, wind, and ice; diastrophism, and vulcanism. Quizzes precede most of these exercises, serving "the triple purpose of inducing the student to prepare in advance for laboratory studies as he would for a recitation, of correlating the lectures and the laboratory assignments, and providing a systematic test of the results of the lectures."

The second special assignment deals with the difficult problem of introducing geologic maps and structures. The problem is handled here by the device of a very complete series of maps which are to be cut out and folded into blocks showing structure-sections on the four sides, as well as areal geology on the top of the block. This ingenious device is undoubtedly full of possibilities, and certainly would be very effective as a teaching method provided the students could be induced to use it. The reviewer has found, however, that there is a tendency to regard such work as a kindergarten device too far below the dignity of a Freshman or Sophomore, and as yet has found no satisfactory way of overcoming this attitude. Some revision of this exercise would seem desirable from that point of view.

The map exercises are so complete and include so many different maps that there is no necessity for giving the same work year after year, or to the different students in the same class. Further, the loose-leaf form of the book makes partial revision a possibility at any time. These two features give the manual a flexibility not found in most other laboratory handbooks.

The ultimate value of this contribution to the literature of laboratory geology rests upon its clear recognition of the need of using every possible device which may contribute to an understanding of the field. Maps, specimens showing ground-water action, models, minerals, etc., are all co-ordinated. Perhaps the next major improvement in such laboratory manuals as this will be the introduction of maps from all parts of the world, using the best obtainable examples of each topographic and geologic feature, regardless of national boundaries, instead of limiting the course to the maps of a single country, as is generally done today.

J. R. V. P., JR.

Report on the Paleontology of the Zanzibar Protectorate. By A. M. DAVIES, L. R. COX, G. M. STOCKLEY, C. J. STUBBLEFIELD, and E. I. WHITE. The Government of Zanzibar, 1927. Pp. 123; plates, 23. £1 1*s*.

The rocks of Zanzibar range in age from Lower Miocene to Recent. A summary of the stratigraphy of the island is given in the Introduction. Most of the forms described are from the Lower Miocene, many are from the Pliocene, and a few are Pleistocene and Recent. New species of foraminifera, molluscs, echinoids, crustaceans, and fish are described. The plates are good and the descriptions ample.

The volume may be obtained from the Crown Agents for the Colonies, 4, Millbank, Westminster, London, S. W. 1.

C. C. B.

Hampshire and Hardy Counties. By J. L. TILTON, W. F. PROUTY, R. C. TUCKER, P. H. PRICE. West Virginia Geological Survey, 1927. Pp. 624; maps 4.

Each county is discussed separately and in detail. Rocks from the top of the Ordovician to Mississippian are represented. The lithology and paleontology of each formation are discussed; the physiography and present geologic processes outlined; and short summaries of the structural geology of each county are given. The economic geology of the region is described at length. Topographic and geologic maps with sections accompany the report. The volume shows careful work and constitutes practically a complete summary of the geologic features of the two counties.

C. C. B.